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R. D. GEORGE, State Geologist

BULLETIN 12

COMMON MINERALS AND ROCKS

THEIR OCCURRENCE AND USES

By
R. D. GEORGE

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LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, Feb. 2, 1917.

Governor Julius C. Gunter, Chairman, and Members of the Advisory Board of the State Geological Survey,

GENTLEMEN: I have the honor to transmit herewith Bulletin 12 of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,
State Geologist.

CONTENTS

Page

Preface 7

Materials of the earth and properties of minerals 9
- Crystallography 12
  - Isometric system 15
  - Tetragonal system 16
  - Hexagonal system 18
  - Orthorhombic system 21
  - Monoclinic system 23
  - Triclinic system 23
- Cleavage, fracture, hardness, specific gravity, diaphaneity, luster, color, streak, associations and occurrence in rocks 25

Rock-making minerals 29
- I. Important minerals of igneous rocks 29
- Ia. Less important minerals of igneous rocks 49
- II. Secondary or metamorphic minerals 52
  - A. Secondary minerals resulting from weathering and decay 52
  - B. Secondary minerals resulting mainly from solution and redeposition in seams and cavities in basic lavas 57
  - C. Secondary minerals resulting from metamorphism other than weathering, commonly dynamic 64
- III. Important minerals of sedimentary rocks 71
- Economic uses of rock-making minerals 75

Non-metallic minerals and their uses 81
- Aluminum, non-metallic minerals 81
- Barium and barium minerals 84
- Beryllium, Glucinum minerals 88
- Boron and boron-bearing minerals 88
- Bromine, and sources of bromine 91
- Calcium and calcium minerals 92
- Carbon and hydrocarbon series of minerals and rocks 93
- Coal, oil, natural gas, asphalt bitumen 95
- Chlorine and its sources 120
- Fuorine and fluorspar 120
- Lithium and lithium minerals 122
- Magnesium and magnesium minerals 126
- Nitrogen and nitrogen compounds 129
- Oxygen 130
- Phosphorus and phosphorus minerals 130
- Potassium and potassium minerals 131
- Silicon and silicon-bearing minerals 135
- Sodium and sodium minerals 136
- Strontium and strontium minerals 142
- Sulphur and sulphur-bearing minerals 144

Page
Gem minerals and semi-precious stones 149

Metallic minerals 157
  Iron and iron minerals 157
  Chromium and chromium minerals 167
  Manganese and manganese minerals 169
  Molybdenum and molybdenum minerals 173
  Nickel and cobalt and their minerals 175
  Titanium and titanium minerals 181
  Tungsten and tungsten minerals 183
  Uranium and vanadium and their minerals 189
  Copper and copper minerals 198
  Lead and lead minerals 208
  Zinc and zinc minerals 216
  Tin and tin minerals 220
  Aluminum and aluminum minerals 222
  Gold and gold minerals 227
  Silver and silver minerals 229
  Platinum, Iridium, Osmium, Palladium 236
  Arsenic and arsenic minerals 239
  Antimony and antimony minerals 242
  Bismuth and bismuth minerals 245
  Tellurium and tellurium minerals 248
  Mercury, Quicksilver, and its ores 249
  Cadmium and the sources of cadmium 251
  Minerals containing cerium, columbium, (niobium), didymium, glucinum, (beryllium), lanthanum, tantalum, thorium, yttrium, zirconium 252

Characteristic reactions of the important elements 258

Important minerals grouped by color 275
  I. Metalliferous minerals having metallic luster 275
  II. Metalliferous minerals of unmetallic luster 277
  III. Non-metallic economic 280
  IV. Gems and semi-precious stones 281
The Common Rocks 283
  Igneous rocks 283
    Granite-Rhyolite family 318
    Granodiorite-Dacite family, including quartz monzonite.... 331
    Diorite-Andesite family 336
    Syenite-Trachyte family, including nephelite syenite and phonolites 352
    Gabbro-Basalt family 359
    Peridotite, Pyroxenite-Limburgite, Augitite and related rocks 367
  Sedimentary rocks 372
    I. Sand and gravel rocks—arenaceous 372
    II. Clay Rocks, argillaceous rocks 378
    III. Sedimentary rocks, chiefly of organic origin 382
      1. Calcareous 382
      2. Carbonaceous 387

Page
3. Siliceous 387
4. Phosphatic 389
IV. Rocks chiefly chemical precipitates 390

Metamorphism, and metamorphic rocks 393
A. Foliated 396
1. The gneisses 396
2. Argillite or slate, phyllite 398
3. Schists 401

B. Non-foliated 405
1. Quartzite 405
2. Crystalline limestones and marbles 406
3. Serpentine and soapstone 410

Building stones 411
Strength 412
Durability 415
Workability 423
Color and fashion 424

The materials of cements, limes, plasters 426

Clays and their uses 430

Materials classified by uses 437
Abrasives; chemical materials; fertilizers; filtering materials, fluxes; fuels and illuminants; glass, porcelain and pottery materials; insulating materials; lubricants; paper-making materials; pigments and paint materials; refractory materials; salines; steel-hardening and steel-cleansing materials; structural materials.

Glossary 445

Index 448

PREFACE

The main purpose of this Bulletin is to describe the commoner minerals and rocks, and furnish the means of recognizing them and knowing their uses. Many valuable geological materials lie unused for want of knowledge of what they are and how they may be used. It is hoped that it will stimulate an interest in, and a search for, valuable geological products.

It did not seem desirable to include tables for the determination of minerals by means of the blowpipe and other tests since there are many inexpensive books available. Among these may be mentioned:

Tables for the Determination of Common Minerals, by W. O. Crosby.

Tables for the Determination of Minerals, by Kraus and Hunt.

Mineral Tables for the Determination of Minerals by Their Physical Properties, by A. S. Eakle.

A simple, compact, inexpensive blowpipe set has been prepared by Professor G. M. Butler and placed on sale by the Denver Fireclay Company.

In preparing this handbook of minerals and rocks the writer has endeavored to present in usable form the important facts regarding the materials of geology. Emphasis has been given to the important minerals and rocks. As a rule, unimportant species have been described only where their intimate relationship to the more important types has made it necessary, or where the possibilities of economic uses have made it desirable.

It is impossible to acknowledge the many sources from which material has been drawn. In the description of minerals, Dana's System of Mineralogy has been used very freely. The publications of the United States Geological Survey have furnished much material bearing on the uses of minerals. And the works of Iddings, Harker, and Kemp have been much used.

MATERIALS OF THE EARTH

AND

PROPERTIES OF MINERALS

MATTER: The substances which make up the earth are called *matter;* and matter may be defined as that which occupies space. It may be solid, liquid or gaseous. When matter has been organized into plant or animal substances it is said to be *organic.* Matter which shows no evidence of having entered into the make-up of plants or animals is called *inorganic.* After the death of plants and animals the organic matter of which they were composed may undergo changes which rob it of all the peculiar features given to it by the living things to which it once belonged. Such matter may be said to have returned to the inorganic form.

CRYSTALLINE MATTER: When a mineral substance or a chemical compound solidifies under favorable conditions, the molecules of which it is composed arrange themselves in a definite order characteristic of the particular substance. Matter so organized is crystalline, whether it shows crystal boundaries or not.

AMORPHOUS MATTER: Under unfavorable conditions of solidification the particles of the same substances may be massed without definite order as are the grains of clay in a lump of mud. Matter solidified in this way is said to be amorphous (without shape).

"EARTH'S CRUST": The term has been handed down from the time when scientists believed that the earth consisted of a molten interior, covered by a solid shell or crust. It is a convenient name for the outer zone of the solid part of the earth. It is composed mainly of mineral matter massed into rocks. But minerals also occur separately, and in bodies not commonly called rocks. Such bodies of minerals include most ore deposits, vein fillings, and similar masses, commonly found in veins, seams and other openings in rocks.

They are of later formation than the containing rock, and are in many cases the results of chemical and other changes in the rocks. The materials of some of these deposits appear to have been brought from deep within the earth by rising waters, vapors and gases, and by volcanic activity.

ROCK: Any mass of matter forming an essential part of the earth. It may be inorganic matter in the amorphous or the crystalline form, or it may be wholly or partly organic.

MINERAL: A natural inorganic substance having a definite chemical composition, and commonly a definite molecular arrangement, which determine its properties and frequently its outward form.

COMPOSITION OF ROCKS: Nearly all rocks are composed of one or more minerals. But a few—such as obsidian, pitchstone and pumice—are composed mainly of mineral matter in an unorganized or amorphous form. Others—such as coal and phosphate rock—consist of organic matter in a more or less mineralized condition.

ELEMENTS: The study of chemistry shows that every variety of matter is composed of one or more substances which have not yet been broken up into simpler forms. These simplest forms of matter are called *elements*. Of the eighty or more elements known to science, only a few play important parts in the make-up of the outer part of the earth, including the land, the sea and the air. The fourteen listed in the table below form over 99 per cent of this outer part of the earth, and eight of the fourteen make up 98 per cent. Oxygen and silicon alone form 76 per cent.

Many of the metallic elements such as gold, silver, copper, lead and zinc, which play such an important part in human activities and human welfare, form such a small part of the earth that their volume would not be missed.

MOLECULE: A molecule is the smallest quantity of an element or compound which can exist in the free state. Molecules are composed of atoms.

ATOM: An atom is the smallest particle of an element which can enter into the make-up of a molecule of any substance.

THE MOST IMPORTANT ELEMENTS

		Symbol	Older Crust (per cent)	Outer Part of Earth—Crust, Air, Sea (per cent)
1.	Oxygen	O	47.02	50.00
2.	Silicon	Si	28.06	26.00
3.	Aluminum	Al	8.16	7.45
4.	Iron	Fe	4.64	4.20
5.	Calcium	Ca	3.50	3.25
6.	Sodium	Na	2.63	2.40
7.	Magnesium	Mg	2.62	2.35
8.	Potassium	K	2.35	2.35
9.	Titanium	Ti	.41	.30
10.	Hydrogen	H	.17	.90
11.	Carbon	C	.12	.20
12.	Phosphorus	P	.09	.08
13.	Sulphur	S	.07	.06
14.	Chlorine	Cl	.01	.175
			99.85	99.715

UNION OF ELEMENTS IN THE FORMATION OF MINERALS

A few minerals consist of single uncombined elements, but by far the greater number are made up of two or more elements combined according to the laws of chemistry. Minerals are divided into broad classes according to the nature of the grouping of the elements in their make-up. Some of the more important groups are as follows:

Native elements, as gold, copper, carbon (in diamond and graphite).

Oxides—formed by the union of oxygen with other elements as silicon dioxide or quartz, SiO_2; iron oxide or hematite, Fe_2O_3.

Carbonates—formed by the union of the oxides of certain elements with carbon dioxide as: calcium carbonate, or calcite, $CaO+CO_2=CaCO_3$.

Silicates—formed by the union of the oxide of silicon (silica), with the oxide of one or more other elements as: the silicate of magnesium, enstatite. $MgO+SiO_2=MgSiO_3$.

Sulphides—formed by the union of sulphur with another element as: iron sulphide, or pyrite, $Fe+S_2=FeS_2$.

Sulphates—formed by the union of the oxide of sulphur with the oxide of another element as calcium sulphate, or anhydrite, $CaO+SO_3=CaSO_4$.

Chlorides—formed by the union of chlorine with another element as sodium chloride, or halite, $Na+Cl=NaCl$.

PROPERTIES OF MINERALS

Minerals are recognized by their *Composition, Crystallization, Cleavage, Fracture, Tenacity, Hardness, Specific Gravity, Diaphaneity, Luster, Color, Streak, Associations* and *Occurrence.* The composition can rarely be determined without the help of chemical tests, and is, therefore, of little aid outside of the laboratory.

CRYSTALLIZATION: A mineral grows by the orderly addition of the mineral substance, molecule by molecule. When this growth is not interfered with, it builds up a *solid* bounded by flat faces meeting at definite angles. Such a *solid* is called a crystal.

CRYSTALLOGRAPHY

(Only a few of the simpler and more usable facts of crystallography are presented. In discussing the crystal form and cleavage of minerals it has been necessary to make use of such facts as are included in the next few pages.)

CRYSTAL: A crystal is matter in which the molecules (minute chemical units) are arranged in a definite order which gives it a well-defined internal structure and a definite external form made up of planes or flat faces meeting at definite angles.

A simple, but somewhat defective, definition would be: A crystal is a naturally formed solid enclosed by more or less smooth planes called faces.

THE FORMATION OF CRYSTALS: There are three principal conditions under which crystals are formed. These are: (1) the solidification of molten matter, (2) precipitation of matter from a solution, and (3) precipitation from vapor.

As a molten rock comes from a volcano it is probably a solution of minerals in minerals. If we take, for example, a molten rock of the composition of granite, it is a solution consisting of molecules of quartz, feldspar, mica and other minerals. As the mass cools the attraction of the mica molecules for one another brings them together and they arrange themselves in a definite order and build up a mica crystal. The feldspar molecules appear to begin building a little later, and the quartz molecules still later. The mica crystal gets a start and may even complete its building while the mass is still molten and before its growth is interfered with by other crystals forming near by.

Crystal building from solution may be illustrated by the formation of salt crystals from the evaporation of a solution of common salt. As the evaporation goes on the water is no longer able to hold all the salt in solution and minute cubical salt crystals begin to form on the walls and bottom of the vessel.

Crystallization from a vapor is well illustrated by the formation of crystals of sulphur about volcanic vents. When native arsenic or native bismuth is strongly heated in a glass tube, open at both ends, minute crystals form on the cooler part of the tube.

Distorted Crystals: If a growing crystal were so placed that the supply of material were exactly the same on all sides, the completed crystal would be *ideal* in form. All faces of the same kind would be of the same size, and exactly the same distance from the center. But such conditions rarely occur in nature. The supply of mineral molecules will be greater on one side than on another, and as a consequence faces of the same kind will differ in size, and will stand at different distances from the center. Such crystals are said to be *distorted.*

Crystal Axes: In studying a crystal it is found convenient to describe the faces by stating the relations they bear to a set of imaginary lines within the crystal. These lines are called the *crystal axes.*

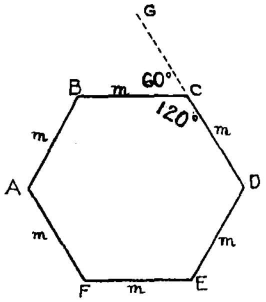
A Crystal Form includes all the faces of the *same kind* which are possible on a crystal of given symmetry. The cube *form* has six faces, the octahedron eight faces. (Fig. 3, 4.)

Combination of Forms: Very commonly two or more different *forms* may occur on the same crystal. This is illustrated by Fig. 6, in which the cube, *a,* and the octahedron, *o,* are combined. Such crystals are called *combinations.*

The Crystal Habit of a mineral is the *form* or *combination* of *forms* commonly occurring in crystals of that mineral. In many cases two or more *forms* occur on the same crystal. (Fig. 9.)

A Crystal Edge is the line or edge formed by the meeting of two crystal faces.

An Interfacial Angle is the angle between two crystal faces which meet or would meet if extended. In Fig. 6, the faces, *a, a* meet at an angle of 90°. In Fig. 9, the faces *a, a* are separated by



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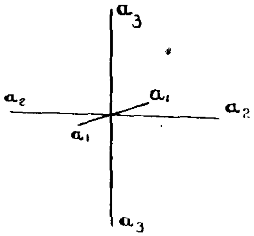

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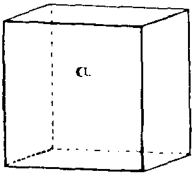

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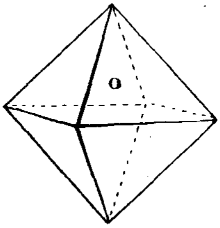

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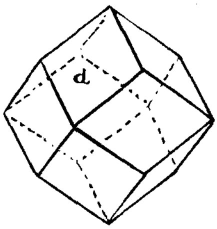

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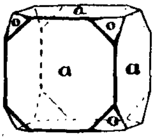

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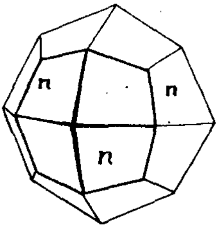

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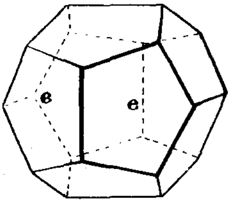

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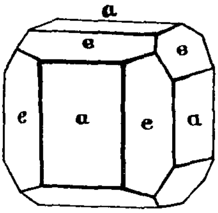

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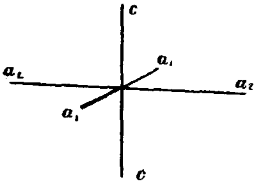

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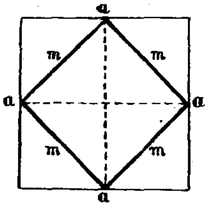

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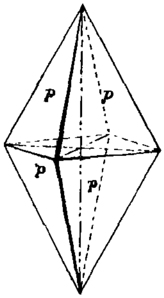


12

the plane *e*, but if they were extended they would meet at an angle of 90°.

For convenience in study it is customary to use, as the interfacial angle, the outer angle formed by the meeting of one of the faces with the other face extended. In Fig. 1, the true interfacial angle is the angle between the face BC and the face CD. But in practice the outer angle between the face BC and the line CG is used. This is known as the *supplement angle.* The true interfacial angle may be found by subtracting the value of the *supplement* angle from 180 degrees.

Constancy of Interfacial Angles: The angles between similar faces on crystals of the same substance are always of the same size.

A Crystal Angle is the solid angle formed by the meeting of three or more crystal faces. The corner of the cube Fig. 3, is a crystal angle.

Twinning is the intergrowth of two or more crystals in such a way that a certain plane or a certain crystal axis is common to the two parts of the twin crystal. (Fig. 47.)

CRYSTAL SYSTEMS: All crystals may be included in six classes or systems. A *system* includes all those crystals whose *forms* may be described by reference to a certain set of crystal axes.

ISOMETRIC SYSTEM

The Isometric System includes all crystals whose *forms* may be referred to a set of three axes of equal length intersecting at right angles. (Fig. 2.) These axes are: a vertical axis, a_3, a right to left axis, a_2, and a back to front axis, a_1. A number of the most important *forms* of the isometric system are illustrated by figures 3 to 9.

Cube: The cube *a,* Fig. 3, is a *form* of the isometric system consisting of six faces which meet, or would meet if extended, at angles of 90 degrees. The faces of an unmodified cube are *crystallographic squares,* but owing to distortion they may not be true squares. *In combinations* such as Fig. 6 the outline of the cube face is modified by the octahedron. Figure 3 might represent a cubic crystal of pyrite, galena, rock salt, or fluorite.

Octahedron: The octahedron *o,* Fig. 4, may represent a crystal of magnetite, galena or fluorite. The *form* consists of eight triangular faces, four of which come to a point about the upper end of the vertical axis and four about the lower end. The edges and solid angles are all alike. In the *ideal* crystal the faces are equilateral triangles but distortion and combination with other *forms* may modify the outlines.

The Dodecahedron or Rhombic Dodecahedron d, Fig. 5, is a *form* made up of twelve rhombic faces meeting at angles of 120 degrees. The faces are *alike* and on *ideal* crystals would be of the same size. *Garnet* frequently forms dodecahedrons, and magnetite less commonly.

Trapezohedron: The trapezohedron *n,* Fig. 7, is a *form* consisting of twenty-four similar faces called trapeziums. (A trapezium is an irregular figure bounded by four straight lines of which no two are parallel.) This trapezohedron is the common form of garnet, analcite and leucite. Magnetite sometimes occurs in trapezohedrons having somewhat different faces and interfacial angles from those of Fig. 7.

The *Pyritohedron* or *Pentagonal Dodecahedron e,* Fig. 8, is a form composed of twelve five-sided faces or pentagons. The pyritohedron and the cube and pyritohedron in combination (Fig. 9), are very common in pyrite.

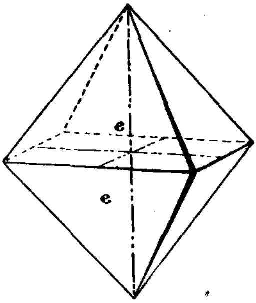
TETRAGONAL SYSTEM

The Tetragonal System includes all crystal *forms* which can be referred to two equal, lateral axes a_1 and a_2, and a longer or shorter vertical axis c all intersecting at right angles. (Fig. 10.) The *forms* of the system are *pyramids, prisms, pinacoids,* and *sphenoids.*

The Axes: Figure 10 illustrates the positions and relations of the axes of the tetragonal system.

Pyramids: The pyramid is a *form* consisting of eight similar triangular faces. Figure 12 shows a pyramid, each face of which cuts both lateral axes and the vertical axis. This is a pyramid of the first order. Figure 13 shows a pyramid, each face of which cuts one lateral axis and the vertical axis and is parallel to the other lateral axis. This is a pyramid of the second order. Two pyramids of the same order, *p* and *u,* Fig. 18, or one of the first and one of the second order may be present on the same crystal.

Prisms: Tetragonal prisms are *forms* consisting of four similar faces parallel to the vertical axis, and having interfacial angles of 90 degrees. The prism of the first order, (Fig. 14) cuts both lateral axes. The prism of the second order, (Fig. 15) cuts one lateral axis and is parallel to the other.



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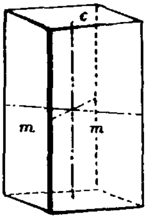

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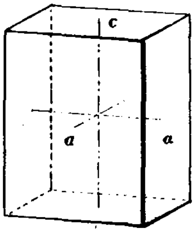

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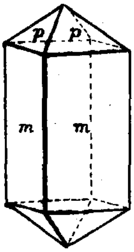

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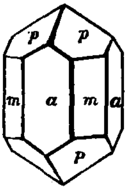

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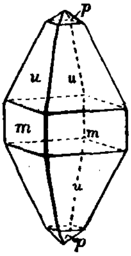

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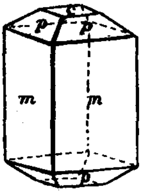

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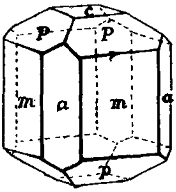

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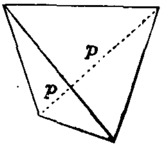

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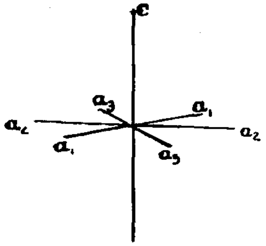

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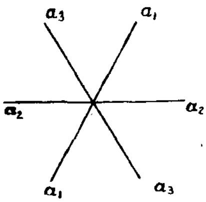

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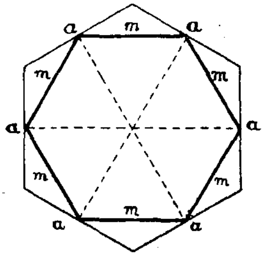

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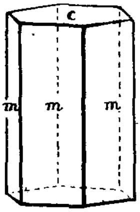

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The relations of the pyramids of the first and second orders to the lateral axes are shown by Fig. 11. The dotted lines are the axes. The heavy lines represent the pyramids of the first order, and the light lines the pyramids of the second order.

The same figure will illustrate the positions and axial relations of the prisms of the first and second orders. The heavy lines represent the prisms of the first order, the light lines those of the second order.

Pinacoids are *forms* consisting of two parallel faces each of which is parallel to two axes. In Figs. 14, 15 the top and bottom faces *c* are basal pinacoids. They stand at right angles to the vertical axis and to the prism faces.

Sphenoid: The sphenoid is a *form* consisting of four similar triangular faces which correspond to two of the upper set of pyramid faces and the alternating two of the lower set of pyramid faces. Fig. 21 represents a sphenoidal crystal of chalcopyrite.

Zircon: Fig. 16 is a combination of the prism *m*, of the first order, and the pyramid *p*, of the first order. In Fig. 17, the prism *a* occupies the place of the interfacial angle between *m* and *m*, and is parallel to the right-left axis a_2. It is therefore a prism of the second order. A pyramid directly over *a* would be a pyramid of the second order. The crystal represented by figure 18 is a combination of the prism *m*, and the pyramids *u* and *p* of the first order.

Vesuvianite: The crystal represented by Fig. 19 shows a combination of the prism *m*, of the first order, the pyramid *p* of the first order, and the basal pinacoid *c*. Fig. 20 is a combination consisting of the prisms of the first and second orders *m* and *a*, the pyramid of the first order *p*, and the basal pinacoid *c*.

Chalcopyrite: The sphenoid is shown by Fig. 21. The faces correspond to four of the faces of the pyramid of the first order.

HEXAGONAL SYSTEM

The Hexagonal System: The *forms* of this system are referred to a set of three equal, lateral axes a_1, a_2, a_3, intersecting at angles of 60° and 120°, and a vertical axis *c*, of different length, at right angles to them, Fig. 22. The *forms* in this system include *pyramids, prisms, pinacoids, rhombohedrons, scalenohedrons,* and *trapezohedrons.*

Axes: The positions and relations of the axes of the hexagonal system are shown by Fig. 22. The relations of the lateral axes are shown in the plan, Fig. 23.

Pyramids: As in the tetragonal system there are pyramids of the first and second orders. The relations of these to the lateral axes are shown in Fig. 24. The dotted lines are the axes; the heavy lines show the position of pyramids of the first order, and the light lines represent the pyramids of the second order.

Prisms: Fig. 24 will also serve to show the relations of the prisms to the lateral axes. The heavy lines show the position of prisms of the first order, and the light lines the prisms of the second order.

Basal pinacoids are parallel to the lateral axes and at right angles to the vertical axis and to the prisms.

Rhombohedrons: A rhombohedron is a *form* composed of six similar faces—three about the upper, and three about the lower end of the vertical axis. When they occur alone they are rhombic in outline as in Fig. 27, but when they occur with certain other forms, their outlines may be modified. as in the rhombohedron *r*, on the quartz crystal, Fig. 29.

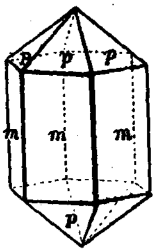
Scalenohedrons: The scalenohedron is a *form* consisting of twelve similar triangular faces—six meeting in a solid angle about the upper end of the vertical axis, and six meeting in the same way about the lower end. The faces are triangles having three unequal sides. (Fig. 28.)

Apatite, Fig. 25. This figure represents one of the common, simple habits of apatite. It is a combination of the hexagonal prism *m*, and the basal pinacoid *c*. Fig. 26 shows an apatite crystal enclosed by the prism *m*, and the pyramid *p*.

Calcite, Figs. 27, 28. Calcite has a great variety of habits. Two are selected to introduce two new *forms*. Fig. 27 shows the negative *rhombohedron e*, a *form* consisting of six similar, rhombic faces—three forming a solid angle above, and three forming a solid angle below the lateral axes. This rhombohedron often combines with the prism and the scalenohedron. In such cases the upper group of three faces will be separated from the lower group.

The *scalenohedron,* Fig. 28, is a very common *form* on calcite. The solid angles which the scalenohedron would form at the ends of the vertical axis are frequently replaced by another form such as the rhombohedron *e*.

Quartz: Fig. 29 presents a combination of the prism *m*, and the positive rhombohedron *r*, and the negative rhombohedron *z*. The faces of the one rhombohedron alternate with those of the other and the result is a triangular outline instead of the usual



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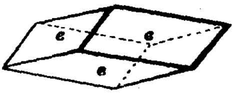

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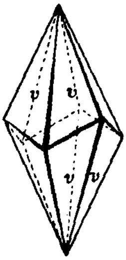

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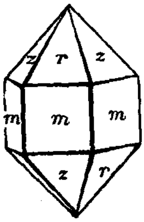

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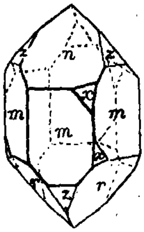

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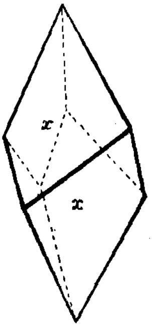

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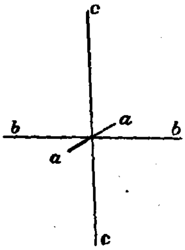

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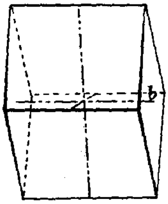

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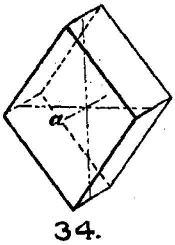

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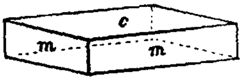

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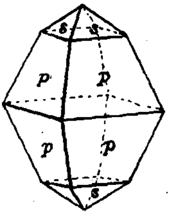

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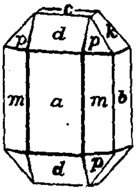


37.

rhombic. Fig. 30 illustrates a combination of the prism *m,* the positive and negative rhombohedrons *r* and *z,* and a rather rare *form* the trapezohedron *z.* The trapezohedron *form,* when developed alone, would give a very irregular crystal enclosed by six trapezium faces, Fig. 31.

ORTHORHOMBIC SYSTEM

The Orthorhombic System includes all crystal *forms* which may be referred to three axes *a, b, c,* of unequal length intersecting at right angles, Fig. 32. Any one of the three axes may be placed in the vertical position. Of the two lateral axes the longer, *b,* passes from right to left, and is called the *macro-axis.* The shorter lateral axis is called the *brachy-axis.* The *forms* of this system include *pyramids, prisms, horizontal prisms* or *domes, pinacoids* and *sphenoids.*

Axes: The relations and relative values of the axes of the orthorhombic system are shown by Fig. 32.

Domes or Horizontal Prisms: The only new *form* appearing in the orthorhombic system is the *dome* or *horizontal prism.* The dome is a *form* consisting of four similar faces parallel to one of the lateral axes, *a* or *b,* and cutting the other lateral axis and the vertical axis. The dome parallel to the macro-axis *b,* Fig. 33, is known as the *macro-dome.* That parallel to the brachy-axis, Fig. 34, is the *brachy-dome.*

Pinacoids: In the orthorhombic system there are three pinacoids: the *basal pinacoid* parallel to the lateral axes and at right angles to the vertical axis and the prisms; the *macro-pinacoid* parallel to the macro-axis *b,* and the vertical axis *c;* the *brachy-pinacoid* parallel to the brachy-axis *a,* and the vertical axis *c.*

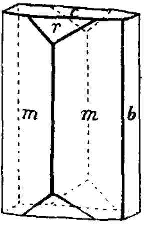
Barite: Fig. 35 shows one of the habits of barite. It is a tabular crystal composed of the prism *m* and the basal pinacoid *c.*

Sulphur: A common habit of sulphur is illustrated by Fig. 36. It is a combination of two pyramids of the first order *p* and *s.*

Olivine: Fig. 37, one of the habits of olivine, is a combination of the prism *m,* the pyramid *p,* the macro-pinacoid *a,* the brachy-pinacoid *b,* the basal pinacoid *c,* the macro-dome *d,* and the brachy-dome *k.*

Staurolite: Fig. 38 presents a combination of the prism *m,* the brachy-pinacoid *b,* the basal pinacoid *c,* and the macro-dome *r.*

Epsomite: Fig. 39 is a combination of the prism *m,* and the sphenoid *z.* The faces of the sphenoid correspond to one-half the planes of the orthorhombic pyramid.



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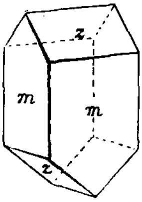

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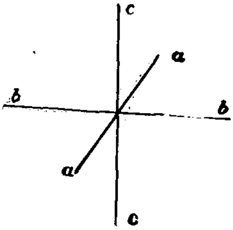

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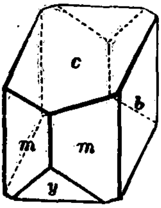

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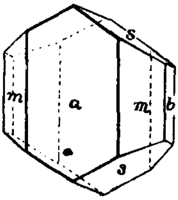

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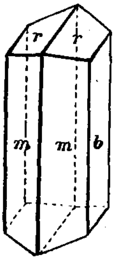

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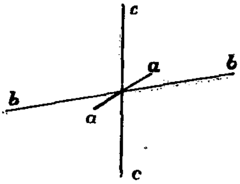

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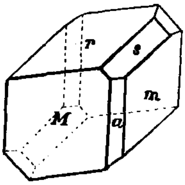

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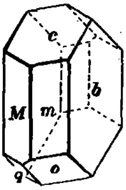

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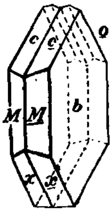

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MONOCLINIC SYSTEM

The Monoclinic System includes those crystals whose *forms* can be referred to three unequal axes, *a, b, c,* of which *a* and *c* intersect at an acute angle behind, and *b* is at right angles to *a* and *c*, Fig. 40. The axis *b* is called the *ortho-axis,* and *a* is the *clino-axis.* The *forms* are *pyramids, prisms, domes* and *pinacoids.*

Axes: Fig. 40 shows the positions and relations of the axes of the monoclinic system.

Pyramids: The pyramids of the monoclinic system consist of four similar faces cutting all the axes. Two of the faces cut the upper end, and two the lower end of the vertical axis. They are unlike the pyramids of the preceding systems in that they cannot enclose space or make a complete crystal without the aid of another *form.*

Prisms: The prisms consist of four similar faces parallel to the vertical axis. They meet the basal pinacoid at angles less or more than a right angle.

Pinacoids: In this system there are three pinacoids, each consisting of two similar faces; the *basal pinacoid* parallel to the lateral axes; the *ortho-pinacoid* parallel to the ortho-axis and the vertical axis; and the *clino-pinacoid* parallel to the clino-axis and the vertical axis.

Orthoclase: A common habit of orthoclase is represented by Fig. 41, which is a combination of the prism *m,* the clino-pinacoid *b,* the basal pinacoid *c,* and the ortho-dome *y.*

Pyroxene: The crystal of pyroxene pictured in Fig. 42 is a combination of the pyramid *s,* the prism *m,* the ortho-pinacoid *a,* and the clino-pinacoid *b.*

Amphibole, Fig. 43*:* This is a common habit of hornblende. It consists of the prism *m,* the clino-pinacoid *b,* and the clino-dome *r.*

TRICLINIC SYSTEM

The Triclinic System includes those crystals whose *forms* are referred to a set of three unequal axes, *a, b, c,* intersecting at angles less and more than right angles, Fig 44. As in the orthorhombic system any one of the axes may be chosen as the vertical axis. The longer lateral axis *b,* is the *macro-axis,* and the shorter *a,* is the *brachy-axis.*

Axes: The positions and relationships of the axes of the triclinic system are illustrated by Fig. 44.

Forms: Since all the axial intersections are oblique, no *form* in this system can consist of more than two faces, and these faces must be parallel.

Pyramids: A triclinic pyramid consists of two parallel faces diagonally opposite one another on the crystal, and cutting all three axes. Since there are four pyramid positions above the lateral axes and four below them, it is evident that there may be four such pairs of parallel faces diagonally opposite each other.

Prisms: The *form* consists of two similar faces parallel to the vertical axis, and parallel to one another. Since it occupies only two of the four prism positions, it is sometimes called a hemi-prism. Another hemi-prism taken with it would be necessary to surround the vertical axis.

Domes: The *form* consists of two similar parallel faces, parallel to one of the lateral axes. That parallel to the brachy-axis is the *brachy-dome*, and the one parallel to the macro-axis is the *macro-dome.*

Pinacoids: The *forms* consist of two similar faces parallel to two axes, and parallel to one another. They are the *basal pinacoid,* the *brachy-pinacoid* and the *macro-pinacoid.*

Axinite, Fig. 45: This is a combination of the two prisms *m* and *M,* the prism *a,* the pyramids *p* and *r,* and the macro-dome *s.*

Albite, Figs. 46 and 47: Fig. 46 shows a combination of the prisms *m* and *M,* the basal pinacoid *c,* the brachy-pinacoid *b,* and the pyramids *o* and *q.* Figure 47 is a twin crystal of albite in which the brachy-pinacoid *b* is common to the two crystals, or parts of the twin. It is therefore called the twinning plane. The macro-dome *x,* the basal pinacoid *c,* the prisms *M* and M, and the pyramid *o* are the other forms present.

CRYSTALS AND CRYSTAL GRAINS

In the solidification of rocks the growth of one mineral is likely to interfere with that of another and prevent the development of perfect crystal forms. But in some molten rock masses (magmas) certain minerals begin to crystallize earlier than others, and may complete their growth with little or no interference, and form crystals. The rocks known as porphyries show this characteristic. For example: Quartz porphyry contains more or less perfect crystals of quartz, while hornblende porphyry is marked by well-defined crystals of hornblende. In others, the earlier minerals may develop to such an extent that some planes of the crystal form may be perfect, while others are absent.

The last mineral substance to solidify occupies the irregular spaces between the minerals already formed. The growth of the crystal will be limited by the space remaining and its boundaries will be the walls of the irregular space it occupies. The arrangement of the molecules in these irregular masses of mineral is the same as that in a perfect crystal of the same mineral. Such imperfect crystals may be called *crystal grains.*

In the granites the order of crystallization, and consequently the degree of perfection of crystal form, is mica, hornblende, feldspar, quartz. From the above facts it is evident that the crystal form is rarely of great importance in determining the minerals composing a rock.

OTHER PHYSICAL PROPERTIES

CLEAVAGE: The orderly arrangement of the molecules in minerals commonly results in the existence of certain planes or directions of weakness, along which they cleave or split with varying degrees of ease and perfection. Some minerals have only one such direction, while others may possess two, three or more.

These planes of cleavage of a mineral are parallel to the faces of one or more of the *crystal forms* which may occur on a crystal of that mineral, and the cleavages are named from the *form* to which they are parallel.

The commoner cleavages in the rock-making minerals are:

Cubic—parallel to the cube.
Pinacoidal—parallel to a pinacoid.
Prismatic—parallel to a prism.
Octahedral—parallel to the octahedron.
Rhombohedral—parallel to a rhombohedron.

Orthoclase has two prominent cleavages—one parallel to the basal pinacoid, and called the *basal pinacoidal cleavage,* or simply, the *basal cleavage,* and one parallel to the clino-pinacoid and called the clino-pinacoidal cleavage, or simply the clino-cleavage. Calcite has a prominent cleavage parallel to the rhombohedron, and called a rhombohedral cleavage.

In breaking a rock, the fracture is likely to follow the cleavages of the contained minerals whenever their directions are nearly parallel with the direction in which the rock breaks. As a result, a freshly broken rock surface commonly shows numerous mineral cleavage planes.

FRACTURE: By this is meant breaking in directions other than those of the cleavage planes. Fracture surfaces may be *Smooth, Even, Ragged, Fibrous, Conchoidal,* (curved like a shell).

TENACITY: The terms commonly used to describe the tenacity of a mineral are: friable, brittle, sectile, malleable, flexible, elastic and tough.

A mineral is friable when it may be crumbled between the fingers. Kaolin.

If a mineral breaks into fragments or powder under a light blow or crumbles into dust when cut it is brittle. Calcite.

A sectile mineral is one which yields a smooth surface when cut with a knife. Gypsum.

A malleable mineral is one which may be flattened by hammering. Native copper.

A mineral which yields to the bending stress and stays bent is flexible. Asbestos.

An elastic mineral yields to a bending stress but when released it returns to its former position.

A mineral is tough when it strongly resists a tearing stress. Muscovite.

HARDNESS: Minerals differ widely in hardness, and as a consequence this property is a valuable aid in identifying them. In the laboratory a set of ten well-known minerals is used as a scale of hardness. These are:

1. Talc.
2. Gypsum.
3. Calcite.
4. Fluorite.
5. Apatite.
6. Feldspar.
7. Quartz.
8. Topaz.
9. Corundum.
10. Diamond.

The important rock-making minerals range from 1 to 7. In work outside the laboratory the following facts are useful:

I. *The thumb nail* is slightly harder than gypsum (2).

II. *A common, soft pin* will scratch calcite (3), but will make little impression on fluorite (4).

III. *Soft iron* will scratch fluorite (4).

IV. *The point of a good knife* will scratch apatite (5), and a very hard one will scratch feldspar (6).

V. *Common glass* lies between feldspar (6) and quartz (7), and is easily scratched by the latter.

SPECIFIC GRAVITY: The specific gravity of a mineral is its density compared with that of water, which is taken as unity. The following table gives the specific gravities of the commoner rock-making minerals:

1.	SILICA MINERALS:		
	Quartz		2.6—2.66
	Chalcedony		
	Agate		
	Amethyst		
2.	FELDSPAR GROUP:		
	Orthoclase	2.57	roughly 2.7
	Albite	2.62—2.65	
	Oligoclase	2.65—2.67	
	Andesine	2.68—2.69	
	Labradorite	2.70—2.72	
	Anorthite	2.74—2.76	
3.	FELDSPATHOID GROUP:		
	Leucite	2.45—2.50	roughly 2.5
	Nephelite	2.55—2.65	
4.	MICA GROUP:		
	Muscovite	2.68	roughly 2.8
	Biotite	2.80—3.10	
	Phlogopite	2.78—2.85	
	Lepidolite	2.80—2.90	
5.	AMPHIBOLES:		
	Hornblende	3.05—3.47	roughly 3.0
	Actinolite	3.00—3.20	
	Tremolite	2.90—3.10	
6.	PYROXENE GROUP:		
	Augite	3.19	roughly 3.2
	Hypersthene	3.40—3.50	
	Bronzite	3.13—3.30	
	Enstatite	3.10—3.13	
7.	OLIVINE	3.27—3.37	
8.	MINERALS, MAINLY SECONDARY:		
	Epidote	3.25—3.50	roughly 2.7
	Serpentine	2.50—2.65	
	Talc	2.70—2.80	
	Kaolinite	2.60—2.63	
	Chlorite	2.65—2.96	
	Calcite	2.72	
9.	TOURMALINE	3.00—3.15	
10.	GARNET	3.50—4.20	

11. IRON MINERALS:

Magnetite	5.20	roughly 5.0
Hematite	5.20	
Pyrite	4.90—5.10	
Ilmenite	4.70—5.10	
Limonite	3.60—4.00	

DIAPHANEITY, BEHAVIOR TOWARD LIGHT: When objects can be seen through a thin chip or slice of the mineral, it is said to be *Transparent.* When the light passes through the mineral, but it is impossible to distinguish objects through it, it is *Translucent.* When no light passes through, the mineral is *Opaque.*

LUSTER: Luster is the appearance of the surface of a mineral, depending upon its character as a reflector of light. The following terms are used to describe lusters:

1. *Metallic:* resembling that of a polished metal. Example: pyrite.
2. *Vitreous:* the luster of broken glass. Example: quartz.
3. *Adamantine:* like that of the diamond.
4. *Pearly:* like that of pearl. Example: talc.
5. *Silky:* like silk. Example: satin spar.
6. *Resinous:* like yellow resin. Example: yellow sphalerite.
7. *Greasy* or oily: like oily glass. Example: nephelite.
8. *Earthy:* like dry earth. Example: kaolin.

COLOR: The color of minerals may be due to:

(a) Chemical composition.

(b) Foreign substances, either included as minute grains or chemically united with the mineral.

The natural colors, due to the chemical composition of the minerals, are an important aid in identifying them.

STREAK: The color of the powdered mineral is often of value in identifying it. When the mineral is used as a crayon on a piece of unglazed porcelain, a streak of mineral powder is left on the porcelain. The streak often differs from the mineral in color.

ASSOCIATIONS AND OCCURRENCE IN ROCKS

A knowledge of the natural grouping of minerals is frequently helpful in identifying them. It also leads to the identification of the rocks. A discussion of the association and occurrence will be found under the various minerals.

ROCK-MAKING MINERALS

I. IMPORTANT MINERALS OF IGNEOUS ROCKS

QUARTZ: An oxide of silicon, SiO_2.

Color: colorless when pure; sometimes white, yellow, brown, green, black.

Luster: vitreous.

Diaphaneity: transparent to opaque.

Crystallization: hexagonal; prisms and rhombohedrons.

Cleavage: none. A platy parting results from pressure.

Fracture: conchoidal to subconchoidal.

Tenacity: brittle.

Hardness: 7.

Streak: white, but very poor.

Specific Gravity: 2.6.

Occurrence: rock-making quartz is generally in irregular grains, and rarely shows crystal outline except in porphyries.

Associations: orthoclase, the first three soda-lime plagioclases, hornblende, micas, rarely pyroxenes, never nephelite.

Rocks: granites and related fine-grained rocks, such as quartz porphyry, rhyolite, nevadite.

Alteration: very resistant, does not decay, and is very slowly dissolved by alkaline solutions.

Tests: B.B. infusible. With soda, fuses with effervescence to a bead varying in transparency with the quantity of soda used. Slowly soluble in borax. Insoluble in all acids except hydrofluoric.

Milky Quartz is a white, nearly opaque variety.

Flint is similar to chalcedony, but is dull and nearly opaque. It breaks with a smooth, conchoidal fracture, has a hardness of about 7, and a specific gravity of 2.6. It occurs chiefly as concretionary nodules in calcareous rocks, but may fill seams and veins in igneous rocks.

Chert is like flint, but less pure, and usually of light color.

Hornstone is another name for chert.

Geyserite and siliceous sinter are described elsewhere.

Fiorite (*Siliceous Sinter*) is formed from the decomposition of the siliceous minerals of volcanic rocks about fumaroles, and as a deposit from hot springs. Commonly gray to white and brown, and sometimes fibrous, probably from its deposition by vegetable agencies. *Pearl Sinter* is similar, but shows pearly luster.

QUARTZ AND SILICA MINERALS DESCRIBED ELSEWHERE: Agate, Agatized Wood, Amethyst, Amethystine, Aventurine Quartz, Bloodstone or Heliotrope, Carnelian or Sard, Cat's Eye, Chalcedony, Chrysoprase, Citrine, False Topaz, Jasper, Moss Agate, Onyx, Opal, Plasma, Prase, Rock Crystal, Bristol Diamonds, Herkimer Diamonds, Lake George Diamonds, Brazilian Pebbles, Rose Quartz, Rutilated Quartz, Sagenite, Sardonyx, Sapphire Quartz, Smoky Topaz, Smoky Quartz, Cairngorm Stone, Morion, Star Quartz, Asteriated Quartz.

THE MICA GROUP

This includes: (1) the Micas proper; (2) the Clintonites or Brittle Micas; and (3) the Chlorites. But as the brittle micas and chlorites are mainly secondary minerals, they are described in another section.

The characteristic features of the mica group are: the highly perfect basal cleavage, yielding thin sheets; the hexagonal outline, and the presence of water of constitution. Most of the micas proper occur both as primary and as secondary minerals.

THE MICAS

MUSCOVITE, potassium mica, $K_2O.2H_2O.3Al_2O_3.6SiO_2$.
BIOTITE, magnesium-iron mica, $(H,K)_2O.2(Mg,Fe)O.Al_2O_3.3SiO_2$.
PHLOGOPITE, magnesium-mica, $(HK,(MgF))_3Al(SiO_4)_3$, or $Al(SiO_4)_3Mg_3KH_2$, Clarke.
PARAGONITE, sodium mica, $Na_2O.2H_2O.3Al_2O_3.6SiO_2$.
LEPIDOLITE, lithium mica, $K,Li(Al(OH,F)_2)Al(SiO_3)_3$.
ZINNWALDITE, lithium-iron mica.
LEPIDOMELANE, iron mica.
ROSCOELITE, vanadium mica.

GENERAL DESCRIPTION

Crystallization: The micas crystallize in the monoclinic system, but their symmetry approaches rhombohedral or orthorhombic.

Cleavage: highly perfect basal, yielding very thin, tough and more or less elastic plates.

Intercrystallization is common between biotite and muscovite, and occurs to some extent between other micas.

Chemically: They are in most cases ortho-silicates of aluminum, with potassium and hydrogen, and often magnesium, ferrous iron, and in some cases ferric iron, sodium, lithium, and other elements.

MUSCOVITE, Potash Mica, White Mica: A potassium-aluminum silicate, $K_2O.2H_2O.3Al_2O_3.6SiO_2$.

Color: colorless, gray, brown, yellow, pale, green, etc.

Luster: vitreous to pearly or silky.

Diaphaneity: transparent to translucent.

Crystallization: monoclinic; rhombic or hexagonal in outline; tabular passing into tapering forms; folia often very small and grouped.

Cleavage: basal, highly perfect. Secondary cleavage is shown by striking a cleavage plate of mica with a pencil point. The mica will split in radiating lines about the point struck.

Fracture: scarcely shown, ragged.

Tenacity: tough.

Hardness: 2—2.5.

Streak: uncolored.

Specific gravity: 2.76—3.

Occurrence: occasionally in six-sided tabular crystals; generally in irregular flakes and scales showing cleavage.

Associations: orthoclase, quartz, biotite, hornblende, albite.

Rocks: granites, felsites, pegmatites, schists, gneisses, arkose.

Alteration: very resistant, but loses its elasticity, luster and transparency.

Tests: Heated strongly in closed tube gives water. B.B. whitens and fuses on thin edges to yellowish glass. Insoluble in acids.

SERICITE, is a silvery-white variety of muscovite occurring in minute silky scales and fibrous bunches. It is a very common alteration product of feldspars, and, as a consequence, is found in altered feldspathic rocks and in metamorphic rocks, such as schists and gneisses. It is also common in arkose.

BIOTITE, Black Mica, Magnesium-Iron Mica: A potassium-aluminum-magnesium-iron silicate, $(HK)_2O.Al_2O_3.2(Mg, Fe)O.3SiO_2$.

Color: green to black, brown in thin plates.

Luster: splendent, to somewhat pearly or silky to vitreous.

Diaphaneity: transparent in very thin sheets, translucent to opaque in thicker plates.

Crystallization: monoclinic; habit tabular or short prismatic with apparently rhombohedral symmetry. Often in disseminated scales.

Cleavage: basal, highly perfect. Secondary cleavage is shown by percussion figure. See under muscovite.

Fracture: scarcely shown, ragged.

Hardness: 2.5—3.

Streak: uncolored.

Specific gravity: 2.7—3.1.

Occurrence: like muscovite.

Associations: quartz, orthoclase, plagioclase, hornblende, muscovite, augite, and other rock-making minerals.

Rocks: granite, syenite, diorite, gabbro, and related fine-grained rocks; gneisses, mica schists, phyllites, slates and other metamorphic rocks.

Alteration: loses its color, luster and elasticity, and changes to chlorite—a soft, green mineral. Occasionally leaches to muscovite, with the separation of magnetite.

Tests: Heated strongly in closed tube gives a little water. Most varieties react for iron after fusion with soda or borax, or salt of phosphorus. B.B. whitens and fuses on thin edges. Boiling sulphuric acid completely decomposes it, leaving the silica in thin scales.

PHLOGOPITE, AMBER MICA, MAGNESIUM MICA: A magnesium-aluminum silicate, with potassium and commonly fluorine, $R'_3Mg_3Al(SiO_4)_3$, where $R' = H, K, Mg$ or F.

Color: yellowish-brown to brownish-red, with something of copper-like reflection.

Luster: pearly, often submetallic on cleavage surfaces.

Diaphaneity: transparent to translucent.

Asterism: Starlike rays are seen when a flame or the sun is viewed through a thin sheet of phlogopite. This is due to the presence of minute needle-like crystals of other minerals (such as rutile and tourmaline), arranged in the direction of the pressure figure, and less distinctly parallel to the percussion figure. See under muscovite.

Crystallization: monoclinic; forms like those of biotite.

Cleavage: basal highly perfect, others rarely seen.
Fracture: ragged.
Hardness: 2.5—3.
Specific gravity: 2.78—2.85.
Occurrence: generally in tabular forms and scales.
Associations: pyroxene, amphibole, serpentine.
Rocks: crystalline limestone, dolomite, and others containing magnesium.
Alteration: to steatite, serpentine and talc.
Tests: the same as for biotite.

PARAGONITE, is a sodium mica, of pearly luster, yellowish to gray, white and greenish color. Translucent in thin sheets. It is not common.

LEPIDOLITE varies in color from white to gray, rose, lilac and pale red. It occurs in granite and gneiss, often with muscovite. It rarely forms large crystals, but is generally massive granular. It associates with tourmaline, spodumene, amblygonite and sometimes occurs in tin veins. (See also under lithium.)

Roscoelite is described under Vanadium.

THE FELDSPARS

The feldspars are silicates of aluminum, with one or more of the bases: potassium, sodium or calcium. They are the most important rock-making minerals, and in volume probably exceed all other rock-makers together. In color, hardness and specific gravity they differ but little. They crystallize in the monoclinic and triclinic systems, but the crystal habits and forms are very similar—differing but a few degrees in corresponding angles. There are two good cleavages—a basal and a pinacoidal—of which the basal is the more perfect. In the monoclinic group the important cleavages meet at 90°. In the triclinic group the angle between them is about 86°, except in microcline and anorthoclase where it is very nearly 90°. This difference in the cleavage angles has led to a division of the feldspars into two groups:

1. Orthoclase—breaking at right angles.
2. Plagioclase—breaking at oblique angles.

In the rock it is difficult to distinguish orthoclase from plagioclase, and it is impossible to distinguish the different plagioclases. The following facts may assist in distinguishing orthoclase and plagioclase:

a. Orthoclase is frequently pink or flesh-colored. Plagioclase is very rarely pink.

b. The cleavage planes of orthoclase meet at an angle of 90°, while those of plagioclase meet at angles slightly less and slightly more than 90°.

c. One of the two good cleavages of plagioclase shows striated surfaces. (Striæ are very fine parallel lines marking the twinning planes.) Microcline and anorthoclase rarely or never show striæ. Orthoclase may show a single twinning line, but never striated surfaces.

d. The feldspars of the more basic rocks—such as the gabbros, diorites and related fine-grained rocks—are predominantly plagioclase. Those of the quartz-rich acid rocks—such as the more siliceous granites—are generally orthoclase. The feldspar of the syenites is predominantly orthoclase. In the less siliceous granites and related fine-grained rocks the feldspar may be about evenly divided between orthoclase and plagioclase.

The simple or pure feldspars are:

1. *Orthoclase or potash feldspar,* a potassium-aluminum silicate, $K_2O.Al_2O_3.6SiO_2$. The orthoclase molecule is $KAlSi_3O_8$.

(Microcline has the same composition but crystallizes in the triclinic system.)

2. *Albite* or *soda feldspar,* a sodium-aluminum silicate, $Na_2O.Al_2O_3.6SiO_2$. The albite molecule is $NaAlSi_3O_8$.

3. *Anorthite, calcium feldspar or lime feldspar,* a calcium-aluminum silicate. The anorthite molecule is $CaO.Al_2O_3.2SiO_2$ or $CaAl_2Si_2O_8$.

A study of the feldspars as rock-making minerals shows that they are rarely pure, but are commonly mixtures of the simple feldspars. Mixtures of orthoclase and albite, and mixtures of albite and anorthite are very common, but mixtures of orthoclase and anorthite are rare.

THE PRINCIPAL FELDSPARS

Orthoclase, $KAlSi_3O_8$. It may be written $K_2O.Al_2O_3.6SiO_2$. Albite molecules are commonly present.

Soda-orthoclase, $(K, Na)AlSi_3O_8$. It may be written $(K, Na)_2O.Al_2O_3.6SiO_2$. A mixture in varying proportions of the orthoclase and albite molecules.

Microcline, $KAlSi_3O_8$. It may be written $K_2O.Al_2O_3.6SiO_2$. Albite molecules are commonly present.

Anorthoclase, $(Na, K)AlSi_3O_8$. It may be written $(Na, K)_2O.Al_2O_3.6SiO_2$. A mixture in varying proportions of the orthoclase and the albite molecules.

Albite, $NaAlSi_3O_8$. It may be written $Na_2O.Al_2O_3.6SiO_2$. Anorthite molecules are commonly present.

Oligoclase / *Andesine* } The albite molecule is in excess of the anorthite molecule.

Labradorite. The albite and the anorthite molecules are present in about equal numbers.

Bytownite. The anorthite molecule is in excess of the albite molecule.

Anorthite, $CaAl_2Si_2O_8$, or $CaO.Al_2O_3.2SiO_2$. Albite molecules are commonly present.

The Orthoclase Group

ORTHOCLASE: A potassium-aluminum silicate, $KAlSi_3O_8$, or $K_2O.Al_2O_3.6SiO_2$.

Color: flesh-pink, white, red, pale yellow, gray.

Luster: vitreous, on cleavage often pearly.

Diaphaneity: Sanidine is transparent; orthoclase is rarely more than translucent.

Crystallization: monoclinic; crystals often prismatic.

Cleavage: basal perfect, prism and pinacoid less so.

Fracture: conchoidal to uneven.

Tenacity: brittle.

Hardness: 6.

Streak: uncolored.

Specific gravity: 2.57.

Occurs: usually as anhedral grains, but also in forms with one or two crystal lines. Cleavage is generally plain. Perfect crystal outlines occur in porphyries and other fine-grained rocks.

Associations: quartz, muscovite, upper plagioclases, hornblende, biotite, nephelite (leucite).

Rocks: granites, syenites and related fine-textured rocks.

Alteration: Becomes dull and earthy, soft and crumbling; loses its potash by solution, in the form of potassium carbonate. Silica separates and disappears, or crystallizes as quartz; water is added, and kaolin is the result. Muscovite (sericite) often forms in very fine flakes or scales.

Tests: B.B. in thin splinters fuses with difficulty to subtransparent glass, coloring the flame pale violet. Insoluble in common acids.

SODA-ORTHOCLASE: This is an orthoclase in which albite molecules replace some of the orthoclase molecules. It fuses more easily than common orthoclase, and gives a less intense violet color to the flame.

HYALOPHANE is a rare feldspar in which barium replaces a part of the potassium.

ADULARIA is a transparent orthoclase. It is rather common in the Cripple Creek region.

SANIDINE is a clear, glassy orthoclase, found in recent acidic lavas such as nevadite, trachyte and some rhyolites.

Plagioclases

A. Potash-soda Plagioclases

MICROCLINE is a potassium-aluminum silicate, differing from orthoclase mainly in belonging to the triclinic crystal system and having its two principal cleavages meeting at angles of 89° 30′ and 90° 30′ instead of 90°. It is multiple-twinned in two directions, forming a rectangular grating visible in thin sections under the microscope, but rarely visible to the naked eye.

Tests: Same as for orthoclase.

ANORTHOCLASE is a potash-soda feldspar, crystallizing in the triclinic system, but, like microcline, having its cleavages meeting at angles differing very little from 90°. It is composed of the orthoclase and albite molecules, with the albite usually in excess. It is rare as a rock-maker

B. Soda-lime Plagioclases

ALBITE: A sodium-aluminum silicate $NaAlSi_3O_3$, or $Na_2O.Al_2O_3.6SiO_2$.

Color: white, sometimes bluish, gray, etc.

Luster: vitreous to pearly on cleavage.

Diaphaneity: transparent to translucent to opaque.

Crystallization: triclinic; but close to orthoclase. Twins are common. Crystals often tabular. In rocks, generally irregular grains, except in porphyries and some gabbros.

Cleavage: same as in orthoclase.

Fracture: uneven to conchoidal.

Hardness: 6—6.5.

Streak: uncolored.

Specific gravity: 2.62—2.65.

Occurrence: same as orthoclase.

Associations: orthoclase, other plagioclases, quartz, hornblende, micas.

Rocks: granites, syenites, diorites, and related fine-grained rocks.

Alteration: Becomes dull and earthy, soft and crumbling; loses soda by formation of sodium carbonate; silica by formation of quartz or in solution; forms kaolin. Muscovite (or sericite) is sometimes formed.

Tests: Fuses at 4 to colorless or white glass, giving an intense yellow (sodium) flame. Not acted upon by acids.

OLIGOCLASE: A sodium-calcium-aluminum silicate.

Color: whitish to grayish-green, otherwise same as albite.

Specific gravity: 2.65—2.67.

Associations: albite, and other plagioclases, hornblende, biotite, etc.

Rocks: granite, syenite, and diorite classes.

Alteration: similar to albite, with addition of calcite, but no muscovite.

Tests: Fuses at 3.5 to a clear or glass-like enamel. Slightly acted upon by acids.

ANDESINE: A sodium-calcium-aluminum silicate.

Hardness: 5—6.

Specific gravity: 2.68—2.69.

Alteration: similar to oligoclase.

Tests: Fuses without much difficulty, giving reddish-yellow flame. Imperfectly soluble in acids.

LABRADORITE: A calcium-sodium-aluminum silicate.

Color: gray, brown, greenish; often shows play of colors.

Diaphaneity: translucent.

Hardness: 5—6.

Specific gravity: 2.7—2.72.

Associations: other lower plagioclases, hornblende, pyroxenes, biotite, olivine, magnetite.

Rocks: gabbros, basalts, and other basic rocks.

Alteration: similar to oligoclase, but the alteration products may include saussurite, (a complex mixture of zoisite, secondary albite, amphibole, garnet, chlorite, and possibly other minerals).

Tests: Fuses at 3 to colorless glass. Hydrochloric acid decomposes the mineral, but generally leaves a residue.

ANORTHITE, LIME FELDSPAR: A calcium-aluminum silicate, $CaAl_2Si_2O_8$, or $CaO.Al_2O_3.2SiO_2$.

Hardness: 6—6.5.

Specific Gravity: 2.74—2.76.

Associated Minerals: pyroxenes, other lower plagioclases, olivine, hornblende, biotite.

Rocks: very basic rocks, gabbros, basalts, and others.

Alteration: same as labradorite.

Tests: Fuses at 5 to colorless glass. Certain anorthites are decomposed by hydrochloric acid, with separation of gelatinous silica.

FELDSPATHOIDS

The so-called feldspathoid group includes minerals of somewhat unlike composition and physical properties, but more or less closely related to the feldspars.

LEUCITE: A potassium-aluminum silicate, $K_2O.Al_2O_3.4SiO_2$.

Color: white, ash-gray, etc.

Luster: vitreous.

Diaphaneity: translucent to opaque.

Crystallization: isometric at 500° C., and pseudo-isometric under ordinary conditions, crystal varying little from the trapezohedron.

Cleavage: very poor.

Fracture: conchoidal.

Tenacity: brittle.

Hardness: 5.5—6.

Streak: uncolored.

Specific gravity: 2.45—2.5.

Occurrence: commonly in fairly good crystal outline, also in irregular grains.

Rocks: recent Vesuvian lavas; Leucite Hills, Wyoming; Absaroka Range, Bearpaw Mountains, Shonkin Sag and Highwoods of Montana; Caribou, B. C.; basalts, tephrites, orendite, leucite phonolites, etc.

Alteration: Loses luster, becomes opaque, loses potash, takes up soda and water, and forms analcite. Also alters to potash feldspar, nephelite and muscovite. Zeolites may be formed.

Difference: harder than analcite, which fuses and yields water.

Tests: B.B. infusible. Cobalt nitrate gives blue color to intensely heated powder. Decomposed by hydrochloric acid without formation of gelatinous silica.

NEPHELITE, ELAEOLITE: A sodium-potassium-aluminum silicate, $3Na_2O.K_2O.4Al_2O_3.9SiO_2$. Na:K generally 4:1 or 5:1.

Color: colorless, white, yellowish to gray and greenish, to blue-gray.

Luster: vitreous to greasy to opalescent.

Diaphaneity: transparent to opaque.

Crystallization: hexagonal, thick six- or twelve-sided crystals (prisms), with plain or modified summits, massive and compact.

Cleavage: prismatic distinct, basal imperfect.

Fracture: subconchoidal. Brittle.

Hardness: 5.5—6.

Streak: uncolored.

Specific gravity: 2.55—2.65.

Occurs: with crystal forms as above; also as anhedral grains.

Associations: orthoclase, augite, hornblende, etc.

Rocks: nephelite syenites, nephelite basalts, etc.

Alteration: commonly to sodalite and analcite, but also to natrolite, thomsonite, etc.

Tests: Fuses at 3.5 to colorless glass. Soluble in hydrochloric acid, with separation of gelatinous silica.

ELAEOLITE: The massive, opaque, or coarsely crystalline mineral of the older rocks is called elaeolite, while the glassy crystallized mineral of recent lavas is called nephelite.

CANCRINITE is a complex hydrous carbonate-silicate of sodium, calcium and aluminum, occurring mainly in nephelite syenites and related rocks, and is probably, in some instances, derived from nephelite by the addition of calcium carbonate. Composition $3H_2O.4Na_2O.CaO.4Al_2O_3.9SiO_2.2CO_2$. It is generally massive, granular; of lemon-yellow to white or gray color, and a subvitreous luster.

SODALITE is a rather rare feldspathoid mineral, $Na_4Al_3ClSi_3O_{12}$, occurring in nephelite syenites and related rocks. *Color:* blue to white or gray. *Luster:* greasy. *Diaphaneity:* transparent to translucent. *Crystallization:* isometric. *Cleavage:* poor. *Fracture:* uneven. Brittle. *Hardness:* 5.5—6. *Specific gravity:* 2.14—2.3. *Economic:* Fine blue, transparent sodalite is used as an ornamental stone, and for cheaper gems.

HAUYNITE is a complex sulphate-silicate of aluminum, sodium and calcium, $Na_2Ca(NaSO_4Al)Al_2Si_3O_{12}$. It is an associate of nephelite and leucite, but is much less common. It frequently shows isometric crystal outlines, has a fair cleavage, a wide range of color in blue, green and yellow tones, is vitreous to greasy in luster, and commonly translucent.

NOSELITE is much like Hauynite, but contains very little lime.

LAZURITE, LAPIS-LAZULI, NATIVE ULTRAMARINE: A sodium-aluminum silicate containing sulphur, $Na_4(NaS_3.Al)Al_2(SiO_4)_3$.

Color: various shades of blue, from azure-blue to greenish-blue.

Luster: vitreous.

Diaphaneity: translucent.

Crystallization: isometric; in cubes and dodecahedrons; also massive and compact.

Cleavage: one poor.

Fracture: uneven.

Hardness: 5—5.5.

Specific gravity: 2.38—2.45.

Occurrence: It is apparently always the result of the metamorphism of limestone.

Tests: B.B. fuses at 3 with swelling to a white glass. With hydrochloric acid yields sulphuretted hydrogen and gelatinous silica. Gives some moisture in the closed tube.

Note.—Lazurite is believed to be made up of the mineral molecule given above, together with a small number of those of hauynite and sodalite.

MELILITE is a rare feldspathoid mineral of variable and uncertain composition, but approximately $6CaO.Al_2O_3.5SiO_2$, with iron replacing some of the aluminum and sodium, and magnesium replacing part of the calcium. *Color*: white, yellow, greenish-yellow, brown. *Luster*: vitreous. *Diaphaneity*: transparent to translucent and opaque. *Crystallization*: tetragonal and octagonal prisms and plates. *Cleavage*: one distinct. *Fracture*: fairly smooth. Brittle. *Hardness*: 5. *Streak*: white. *Specific gravity*: 2.9—3.1. *Tests*: B.B. fuses at 3 to yellowish or greenish glass. Decomposed by hydrochloric acid with separation of gelatinous silica. *Occurrence*: *commonly* well-formed crystals in certain basaltic rocks—melilite basalt, and others.

THE PYROXENES AND AMPHIBOLES

The pyroxenes and the amphiboles are closely related in chemical composition and physical properties. In crystallization each group has representatives in the orthorhombic, the monoclinic and the triclinic systems. In the rock specimen it is difficult to distinguish the pyroxenes from the amphiboles, but a few facts will be of service.

a. The cleavage faces of pyroxene proper meet at angles of 87° and 93°, while those of amphibole proper meet at angles of 56° and 124°.

b. Amphibole has a much better cleavage than pyroxene.

c. Pyroxene crystals are more likely to be short and stout, while those of amphibole are commonly long, prismatic.

d. Bronzite and enstatite often show a fibrous structure, while actinolite and tremolite frequently occur in slender crystals and felty groups.

e. The pyroxenes are more common in the very basic rocks, in which quartz, orthoclase and muscovite are rare. The amphiboles occur in the more acidic rocks, with quartz and orthoclase, and occasionally muscovite.

f. Massive pyroxene is generally lamellar or granular, while massive amphibole is likely to be columnar and fibrous.

g. Amphiboles have a more brilliant luster and retain it better than pyroxenes.

h. The bronzy, submetallic luster often characterizes bronzite and enstatite, while the vitreous luster is common in actinolite and tremolite.

PYROXENE GROUP

ENSTATITE AND BRONZITE: Silicates of magnesium, with more or less iron.

a. Enstatite, $MgO.SiO_2$: A magnesian silicate.

b. Bronzite, $(Mg,Fe)O.SiO_2$: A magnesian silicate with some iron.

Color: yellowish to greenish-yellow to olive green and brown.

Luster: pearly to vitreous on cleavage faces, to weakly metallic.

Diaphaneity: translucent to opaque.

Crystallization: orthorhombic; crystals rare, prismatic, massive, fibrous and lamellar.

Cleavage: M (prism) rather good, parting parallel to *b* and *a*.

Fracture: uneven. Brittle.

Hardness: 5.5.

Streak: uncolored to grayish.

Specific gravity: 3.1—3.3.

Occurs: irregular, stout grains, sometimes showing one or more crystal faces.

Associations: augite, olivine, basic plagioclases, hornblende, etc.

Rocks: peridotites, gabbros, kimberlite, norite.

Alteration: Loses luster, becomes dull and granular or fibrous, and commonly changes to a fibrous pyroxene, approaching serpentine in composition.

Tests: B.B. almost infusible. Very thin splinters are rounded on the edges. Insoluble in hydrochloric acid.

HYPERSTHENE: An iron-magnesium silicate, $(Fe,Mg)O.SiO_2$.

Color: dark brownish-green to brown, to black or gray-black.

Luster: somewhat pearly on cleavage, and sometimes weakly metallic.

Diaphaneity: nearly opaque.

Crystallization: orthorhombic; crystals rare; prismatic, often tabular.

Cleavage: basal perfect, *m* and *a* distinct, but interrupted.

Fracture: uneven. Brittle.

Hardness: 5.6—6.

Streak: gray to brownish-gray.

Specific gravity: 3.4—3.5.

Occurs: stout, irregular grains; may show some crystal boundaries.

Associations: labradorite, augite, hornblende, olivine.

Rocks: gabbro, norite, andesite.

Alteration: Loses luster, becomes earthy, brownish-green, and changes to fibrous hornblende, and sometimes to compact hornblende.

Tests: B.B. fuses to a black enamel, and on coal yields a magnetic mass. The fusibility increases with the iron present. Partly decomposed by hydrochloric acid.

DIOPSIDE, MALACOLITE. Calcium-magnesium pyroxene, $CaO.MgO.2SiO_2$.

Color: white, sometimes colorless, yellowish, grayish-white to pale green to dark green and greenish-black.

Luster: vitreous to resinous, often dull.

Diaphaneity: sometimes transparent, but usually opaque.

Crystallization: monoclinic; prismatic crystals.

Cleavage: The same as that of augite, but the variety diallage has more perfect pinacoidal parting or cleavage than augite.

Fracture: uneven to conchoidal. Brittle.

Hardness: 5—6.

Streak: uncolored to gray and grayish-black.

Specific gravity: 3.2—3.38.

Occurs: prismatic crystals, but more commonly granular, lamellar or massive.

Associated minerals: other pyroxenes, amphiboles, plagioclases, biotite, olivine, dolomite, calcite, etc.

Rocks: gabbros, peridotites, diorites, lamprophyres, crystalline schists, magnesian marbles, etc.

Alteration: similar to augite.

PYROXENE: A calcium-magnesium-iron silicate, $Ca(Mg, Fe)SiO_6$, or $CaO.(Mg, Fe)O.2SiO_2$. Intermediate in composition and physical properties between diopside and hedenbergite.

Color: light to dark green.

Luster: vitreous.

Diaphaneity: opaque.

Crystallization: monoclinic; stout prisms of almost rectangular cross section or sometimes rudely octagonal.

Cleavage: prismatic, imperfect, with cleavage faces making angles of 93 and 87 degrees. A basal parting is often well developed.

Fracture: uneven.

Hardness: 5—6.

Streak: gray to grayish-black.

Specific gravity: 3.1—3.5.

Occurs: in crystal grains, often approaching complete crystal outlines.

Associated minerals: Hornblende, plagioclase, particularly labradorite, biotite, olivine.

Rocks: gabbros, dolerites, peridotites, pyroxenites, some syenites and the fine-grained rocks corresponding.

Alteration: see augite.

Tests: Fuses without difficulty to greenish or brownish glass, varying in depth of color with the amount of iron present. If much iron is present the fused mass may be magnetic.

HEDENBERGITE: A calcium-iron pyroxene, $CaFe(SiO_3)_2$, with occasionally manganese.

Color: black.

Luster: weakly vitreous to resinous.

Diaphaneity: opaque to weakly translucent in thin plates.

Crystallization: monoclinic prisms, and granular forms.

Cleavage: prismatic very good.

Fracture: uneven. Brittle.

Hardness: 5.5.

Streak: gray.

Specific gravity: 3.5.

Occurrence: as a rock-making mineral in the intermediate and basic rocks.

Tests: B.B. fusible at about 5; reacts for iron, and when much iron is present becomes magnetic.

AUGITE: Chiefly a calcium-magnesium silicate, with iron and aluminum, $CaO.MgO.2SiO_2$ with $(Mg,Fe)O.(Al,Fe)_2O_3.SiO_2$.

Color: greenish, brownish-black and black.

Luster: vitreous to resinous, often dull.

Diaphaneity: opaque.

Crystallization: monoclinic, short, thick, prismatic crystals or tabular parallel to the base. Prisms approach squares and octagons.

Cleavage: prismatic, *m* rarely perfect, generally interrupted, orthopinacoidal, *a* less perfect. Parting due to twinning, is often well developed.

Fracture: uneven to conchoidal. Brittle.

Hardness: 5—6.

Streak: gray to grayish-black.

Specific gravity: 3.2—3.6.

Occurs: commonly in stout crystal grains showing two or more crystal faces.

Associated minerals: hornblende, plagioclase of lower group, biotite, olivine.

Rocks: gabbros, peridotites, diorites, syenites and corresponding lava forms.

Alteration: Loses its luster, becomes earthy, brownish-green and commonly forms scaly and fibrous chlorite, with epidote, calcite and quartz. Hornblende is a common alteration product.

Tests: Fusibility varies, according to the amount of iron, from 2.5 to 3.75. Those rich in iron yield a magnetic globule when fused on charcoal. Some varieties yield a blue-green color when fused with soda (manganese). Rarely decomposed by acids.

ACMITE and ÆGIRITE: Sodium-iron pyroxene, $Na_2O.Fe_2O_3.4SiO_2$. The two minerals differ mainly in their crystal forms.

Color: brown, reddish-brown, green.

Luster: vitreous to resinous.

Crystallization: monoclinic; acmite in long prismatic, vertically striated forms, with acute terminations; ægirite in prismatic, blunty terminated forms, and in bunches and groups of slender crystals.

Cleavage: prismatic, fair.

Fracture: uneven. Brittle.

Hardness: 6—6.5.

Streak: gray to greenish-gray.

Specific gravity: 3.5—3.55.

Occurrence: prisms commonly prominent, irregular grains.

Associated minerals: nephelite, leucite, other pyroxenes, hornblende, olivine, plagioclase, biotite.

Rocks: nephelite syenites, phonolites; some syenites and granites.

Alteration: loses luster; color becomes rusty from separated iron.

Tests: B.B. fuses easily to a black magnetic globule, coloring the flame deep yellow (sodium). Slightly acted upon by acids. With soda and borax reacts for iron.

RHODONITE is a metasilicate of manganese, $MnSiO_3$, resembling pyroxene. It occurs in tabular crystals with rounded edges, and in massive and compact forms without crystal boundaries. Two good cleavages; conchoidal fracture; very tough when compact; hardness 5.5—6.5; density 3.4—3.7; vitreous to pearly; brownish-red to pink and rose; transparent to translucent and opaque. Specimens of fine color and transparent to subtransparent are cut for gems and ornamental stones.

AMPHIBOLE GROUP

TREMOLITE: A calcium-magnesium silicate, $CaO.3MgO.4SiO_2$. (Ferrous iron may replace magnesium up to 3 per cent.) Nearly always secondary.

Color: sometimes transparent and colorless, white to dark gray and bluish-gray.

Luster: vitreous to pearly.

Diaphaneity: transparent to translucent.

Crystallization: monoclinic; long-bladed or short stout; often in aggregates; long and thin columnar or fibrous.

Cleavage: prismatic perfect, pinacoidal fair.

Fracture: subconchoidal, uneven. Brittle.

Hardness: 5—6.

Streak: uncolored.

Specific gravity: 2.9—3.1.

Occurs: groups and bunches of imperfect forms, often bladed, frequently fibrous.

Associations: calcium carbonate and magnesium carbonate in calcareous rocks.

Rocks: impure limestones and other rocks containing calcium and magnesium, as a product of metamorphism.

Alteration: rarely seen. Talc is sometimes formed.

Tests: Fuses with some difficulty to an enamel. Not soluble in acids.

ACTINOLITE: A calcium-magnesium-iron silicate, $CaO.3(Mg,Fe)O.4SiO_2$. Nearly always secondary.

Color: green, owing to presence of ferrous iron.

Luster: vitreous to pearly. One variety in long, green crystals is called "glassy actinolite."

Diaphaneity: sometimes transparent.

Crystallization: monoclinic; crystals either short- or long-bladed, fibrous acicular.

Cleavage: prismatic perfect, *a* and *b* sometimes distinct.

Fracture: subconchoidal, uneven. Brittle.

Hardness: 5—6.

Streak: uncolored to very pale.

Specific gravity: 3—3.2.

Occurs: grouped in sheaf-like and radiating bundles of acicular crystals and fibers; also singly.

Associated minerals: hornblende, quartz, feldspar down to andesine, biotite.

Rocks: altering rocks containing the ferromagnesian minerals, and metamorphic, particularly schists.

Alteration: rarely seen, but the product appears to be serpentine and calcite.

Tests: Fuses with little difficulty to a greenish enamel, which may be slightly magnetic. Not acted upon by acids.

HORNBLENDE: Chiefly a calcium-iron-magnesium silicate, with some sodium and aluminum, $CaO.3(Mg,Fe)O.4SiO_2$ with $Na_2O.Al_2O_3.4SiO_2$ and $2(Mg,Fe)O.2(Al,Fe.)_2O_3.2SiO_2$.

Color: bright to dark green, bluish-green to black, brown.

Luster: vitreous to pearly on cleavage faces. Fibrous varieties often silky.

Diaphaneity: opaque.

Crystallization: monoclinic, prismatic, usually terminated by low clino-dome; prism sometimes distinct.

Cleavage: prismatic highly perfect.

Fracture: subconchoidal, uneven. Brittle.

Hardness: 5.6.

Streak: grayish to dark gray.

Specific gravity: 3—3.47, varying with composition.

Occurs: elongated grains, commonly showing parallel sides and generally ragged ends.

Association: quartz, feldspars (orthoclase and plagioclase), biotite (muscovite).

Rocks: granites, syenites, diorites, gabbros, and corresponding fine-grained forms.

Alteration: loses luster, becomes earthy, and changes to chlorite, epidote, calcite and quartz.

Tests: Fuses to a magnetic mass—sometimes globular. Not acted upon by acids.

RIEBECKITE: A sodium-iron silicate related to arfvedsonite and corresponding closely to acmite among the pyroxenes, $2Na_2O.Fe_2O_3.4SiO_2.2FeO.2SiO_2$.

Color: black.

Luster: vitreous.

Diaphaneity: opaque.

Crystallization: monoclinic, elongated, striated prismatic crystals, rarely terminated.

Cleavage: primatic perfect.

Fracture: uneven to conchoidal.

Hardness: 6.

Streak: gray to blue-gray.

Specific gravity: 3.3.

Occurrence: bedded crystals and prismatic grains.

Associations: other soda-rich ferromagnesian silicates, nephelite, leucite, alkali feldspars.

Rocks: nephelite syenites and related rocks. From St. Peters Dome, Colorado.

Alteration: See arfvedsonite.

Tests: same as for arfvedsonite.

ARFVEDSONITE: A silicate of sodium, calcium and iron, $4Na_2O.3CaO.14FeO.(Al,Fe)_2O_3.21SiO_2$.

Color: black to deep greenish-black.

Luster: glassy.

Diaphaneity: translucent in thin splinters.

Crystallization: monoclinic; prismatic and prismatic aggregates, tabular, seldom terminated.

Cleavage: prismatic perfect, pinacoidal fair.

Fracture: uneven. Brittle.

Hardness: 6.

Streak: gray to deep blue-gray.

Specific gravity: 3.44.

Occurrence: prismatic grains seldom terminated, commonly two or three times as long as thick.

Associations: other soda-bearing amphiboles, nephelite, leucite, alkali feldspars.

Rocks: nephelite syenites, phonolites, some syenites and granite.

Alteration: Luster becomes dim, color green to rusty-green to brown.

Tests: B.B. fuses easily with swelling to a black magnetic globule, coloring the flame yellow (sodium). With soda and borax reacts for iron and manganese. Not acted upon by acids.

OLIVINE, CHRYSOLITE, PERIDOT: A ferromagnesian silicate, $2(Mg,Fe)O.SiO_2$. Mg:Fe varies from 16:1, 12:1 to 2:1 in hyalosiderite, and so ranging from fosterite to fayalite.

Color: green, olive-green to brownish and red, etc., from oxidation of iron.

Luster: vitreous.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic.

Cleavage: basal rather distinct, pinacoidal less so.

Fracture: conchoidal.

Tenacity: brittle.

Hardness: 6.5—7.

Streak: rarely yellowish, generally uncolored.

Specific gravity: 3.27—3.37 (3.37 for hyalosiderite).

Occurs: Often shows crystal outline; also irregular, massive and compact granular forms.

Associations: augite and other pyroxenes, lower plagioclases, biotite, hornblende; iron ores, serpentine and other secondary minerals in metamorphic rocks.

Rocks: gabbros, basalts, peridotites, etc.; metamorphic rocks with limestone and dolomite.

Alteration: (a) to serpentine and iron oxides, and calcite; (b) to a red, scaly or lamellar mineral called iddingsite, and hematite; (c) to chlorite.

Tests: B.B. loses color, but rarely fuses. Varieties rich in iron, such as hyalosiderite, fuse to a magnetic gobule. With soda and borax react for iron. Hydrochloric and sulphuric acids decompose it with separation of gelatinous silica.

II. LESS IMPORTANT MINERALS OF IGNEOUS ROCKS

ZIRCON: A silicate of zirconium, $ZrO_2.SiO_2$.

Color: pale reddish-brown, to yellowish and greenish-gray.

Luster: adamantine.

Diaphaneity: transparent to translucent and opaque.

Crystallization: tetragonal; square prisms, commonly terminated by pyramids.

Cleavage: rather poor.

Fracture: conchoidal, smooth.

Hardness: 7.5.

Streak: uncolored.

Specific gravity: 4.68.

Occurrence: perfect crystals and irregular grains.

Associations: quartz, orthoclase, plagioclase, micas, hornblende.

Rocks: granites and others containing much soda, crystalline limestones, schists and gneisses.

Alteration: very resistant.

Colorado localities: Saint Peters Dome and other localities near Pikes Peak.

TITANITE, SPHENE: A silicate of calcium and titanium, $CaO.TiO_2.SiO_2$.

Color: shades of brown, gray, yellow, red, green and black.

Luster: adamantine to resinous and vitreous.

Diaphaneity: transparent to opaque.

Crystallization: monoclinic, in wedge-shaped, flattened and prismatic crystals, and in twins in the shape of a cross.

Cleavage: one fair and one poor.

Fracture: easy parting, due to twinning.

Hardness: 5—5.5.

Streak: white to slightly reddish.

Specific gravity: 3.4—3.56.

Occurrence: commonly in crystals and crystal grains, but sometimes massive, granular and compact.

Associations: orthoclase, plagioclase, quartz, micas, hornblende, pyroxene, chlorite, apatite, scapolite and zircon.

Rocks: hornblende granites, syenites, nephelite syenites, diorites, schists, gneisses and limestones.

Tests: B.B. generally changes color and fuses at 3, with swelling, to a dark-colored glass. With borax the glass is clear yellowish-green. Imperfectly dissolved by hydrochloric acid. When tin is added and the solution boiled a violet solution results. Completely decomposed by sulphuric acid.

Colorado localities: in the syenites of the Front Range; in the San Juan; in the Monarch area of Chaffee County; at Cripple Creek; at Sunset, Boulder County, etc. Astrophyllite, a related mineral, occurs at St. Peters Dome and Pikes Peak.

TOURMALINE: A complex silicate of boron and aluminum, with either magnesium, iron or the alkali metals prominent.

Color: black, brownish-black, bluish-black; sometimes blue, green and red.

Luster: vitreous to resinous.

Diaphaneity: commonly opaque, but may be transparent or translucent.

Crystallization: hexagonal; prismatic, often slender, commonly showing nine faces, but sometimes six or only three.

Cleavage: two poor cleavages.

Fracture: subconchoidal to uneven.

Tenacity: brittle and sometimes friable.

Hardness: 7—7.5.

Streak: uncolored.

Specific gravity: 2.98—3.2.

Occurs: commonly in well-defined crystals, often in bunches and radiating groups. Sometimes massive, compact and granular.

Association: the minerals of granite and gneiss and those of schists.

Rocks: granite, gneiss, pegmatite, schist, and rocks affected by fumarolic action.

Alteration: rarely seen in altered condition.

Tests: Varieties containing magnesia without iron fuse easily to a white glass or slag; those with iron are more difficultly fused. The iron variety is barely fusible. Certain varieties are infusible. Fused with a mixture of potassium bisulphate and fluorite gives a pale-green flame (boron). Insoluble in acids. Gelatinzes after strong ignition.

ZOISITE, THULITE: A hydrous silicate of calcium and aluminum, closely related to epidote, $4CaO.3Al_2O_3.6SiO_2.H_2O$.

Color: gray to white to yellowish-brown to green and pink.

Luster: vitreous to pearly.

Diaphaneity: transparent to almost opaque.

Crystallization: orthorhombic; prismatic, striated vertically.

Cleavage: one very perfect.

Fracture: uneven to subconchoidal. Brittle.

Hardness: 6—6.5.

Streak: uncolored.

Specific gravity: 3.25—3.37.

Occurrence: crystals and crystal grains, massive and columnar.

Associations: amphiboles, corundum, plagioclase.

Rocks: metamorphic rocks derived from basic igneous rocks rich in lime-bearing plagioclase.

Alteration: very stable.

Tests: B.B. swells and fuses at 3.5 to a white enamel. After strong heating, the powdered mineral is decomposed by hydrochloric acid, with the separation of gelatinous silica. The unburnt mineral is not acted upon by acids.

AXINITE is a borosilicate of aluminum and calcium, with some iron and manganese. *Color*: clove-brown to plum-blue, pearl-gray and honey-yellow. *Luster*: highly vitreous. *Diaphaneity*: transparent to subtranslucent. *Hardness*: 6.5—7. *Specific gravity*: 3.27—3.29. *Cleavage*: three distinct. *Fracture*: conchoidal. *Crystallization*: triclinic; broad, acute-edged; sometimes prismatic. *Tests*: Fuses easily, swelling and coloring flame pale green, and forming a green to black glass. With borax in O.F. gives amethystine bead. *Use*: chiefly as a gem or ornament.

LESS IMPORTANT MINERALS OF IGNEOUS ROCKS DESCRIBED ELSEWHERE: Pyrite, Magnetite, Ilmenite, Apatite, Rutile, Garnet.

III. SECONDARY OR METAMORPHIC MINERALS

Under the action of weathering, heat, pressure and moisture, rocks are chemically broken up, and new or secondary minerals are formed. These are commonly simpler and more stable than the minerals or other rock matter from which they are derived. Since all the changes which take place in the constitution of rocks may be included under the term "metamorphism," the minerals formed in these changes may be called metamorphic minerals. Many of the minerals already described occur as secondary products, but are much more important as primary rock constituents. Of the following, only a few are known as primary minerals, while they are all of frequent occurrence as secondary products.

A. SECONDARY MINERALS RESULTING FROM WEATHERING AND DECAY

SERPENTINE: A hydrous magnesium silicate, $2H_2O.3MgO.2SiO_2$. FeO often replaces part of the MgO.

Color: leek-green, oil-green, blackish-green, brownish, reddish, yellowish, whitish.

Diaphaneity: translucent to opaque.

Crystallization: crystals of serpentine are not known, but it sometimes forms good pseudomorphs. Fibrous, foliated, but folia rarely separable, usually massive, but under the microscope it is seen to consist in most cases of a felty, fibrous mass, fine-granular.

Cleavage: ortho-pinacoidal, good.

Fracture: conchoidal or splintery.

Hardness: 2.5—4 or 5.

Streak: white, with somewhat glassy appearance.

Specific gravity: 2.5—2.65; fibrous varieties lower.

Occurrence: commonly fibrous masses, but sometimes granular, occupying space made by alteration of other minerals.

Associations: always secondary, from rocks rich in magnesium. It is often accompanied by carbonates: dolomite, magnesite, calcite, etc., giving serpentine marbles, verd antique, ophiolite, ophicalcite, etc. Serpentine marble is any serpentine rock cut and polished.

Rocks: yielding serpentine: peridotites, gabbros and others containing ferromagnesian minerals.

Alteration: Serpentine is a very stable end product.

Tests: Yields water in the closed tube. B.B. thin splinters fuse on the edges. Reacts for iron. Hydrochloric and sulphuric acids decompose it.

Economic: See asbestos and serpentine rocks.

CLINTONITES OR BRITTLE MICAS

MARGARITE, $H_2O.CaO.2Al_2O_3.2SiO_2$, is a calcium-bearing, brittle mica or clintonite, of pink, gray or yellow color, a pearly luster, a hardness of 3.4—4.5, and a specific gravity of 3. It is found associated with tourmaline, staurolite, garnet, and other secondary minerals.

OTTRELITE is a manganese-bearing mica, possibly $H_2O.(Fe,Mn)O.Al_2O_3.2SiO_2$. It is dark gray to black, fuses with difficulty, and reacts for iron and manganese.

CHLORITE GROUP

The group includes a series of secondary minerals derived mainly from the aluminum-bearing ferromagnesian minerals. They are hydrous silicates of aluminum, ferrous iron and magnesium. They are in some respects similar to the micas. They crystallize in the monoclinic system, and, like the micas, have a hexagonal outline, and a prominent basal cleavage. The laminæ are tough, but inelastic. The prevailing color is green. Only clinochlore and penninite occur in distinct crystals, while corundophilite and prochlorite occur in distinct cleavage masses. The other varieties are less well defined, occur in scales, fibers, or masses and earthy forms.

As developed from the alteration of the ferromagnesian minerals in weathering rocks, the chlorites are soft, crumbling, generally dull, olive-green, scaly, earthy-looking minerals.

CLINOCHLORE: Normally $Al_2O_3.5MgO.3SiO_2.4H_2O$, but ferrous iron commonly replaces part of the magnesia.

Color: deep grass-green to olive-green; pale green to yellowish and white; occasionally rose-red.

Luster: on fresh cleavage faces inclines to pearly.

Diaphaneity: transparent to translucent.

Crystallization: monoclinic, in tabular hexagonal forms, sometimes built up into prismatic forms; triangular and twelve-sided prisms occur; in altering rocks it is massive, scaly, granular and earthy.

Cleavage: basal, perfect.

Fracture: The laminæ are flexible and tough, but scarcely elastic.

Hardness: 2—2.5.

Streak: pale greenish to uncolored.

Specific gravity: 2.65—2.78.

Occurrence: mainly in altering rocks containing the ferromagnesian minerals, such as granites, diorites, gabbros, biotite schists, etc.

Tests: Yields water. B.B. in platinum forceps whitens and fuses on thin edges to grayish-black glass. Completely decomposed by sulphuric acid.

PENNINITE: Essentially the same composition as clinochlore, $Al_2O_3.5(Mg,Fe)O.3SiO_2.4H_2O$.

Color: various shades of green, reddish, violet, rose-red, pink, and occasionally almost white.

Luster: pearly on cleavage faces.

Diaphaneity: transparent to translucent.

Crystallization: monoclinic, but rhombohedral in habit, in tabular blocks and tapering prisms; also massive, and in aggregations of scales.

Cleavage: basal, perfect.

Tenacity: laminæ flexible, not elastic.

Hardness: 2—2.5.

Streak: pale gray to white.

Specific gravity: 2.6—2.85.

Occurrence: It is rather common in rocks in which the ferromagnesian minerals are altering.

Tests: In closed tube gives water. Folia fuse with difficulty. Completely decomposed by sulphuric acid. Partially so by hydrochloric.

CORUNDOPHILITE: $11MgO.4Al_2O_3.6SiO_2.10H_2O$.

Color: various shades of green.

Luster: cleavage surfaces somewhat pearly.

Diaphaneity: transparent to nearly opaque.

Crystallization: monoclinic in six-sided and twelve-sided tabular forms and low prisms.

Cleavage: basal, perfect.

Hardness: 2.5.

Specific gravity: 2.9.

Occurrence: with emery and corundum.

TALC, STEATITE, SOAPSTONE: A hydrous magnesium silicate, $H_2O.3MgO.4SiO_2$.

Color: apple-green to white or silvery-white, brownish to blackish-green, etc., when impure.

Luster: pearly on cleavage surface.

Diaphaneity: subtransparent to translucent.

Crystallization: orthorhombic or monoclinic; rarely in tabular crystals, usually foliated massive, sometimes globular and stellated groups, also granular massive; fibrous and compact cryptocrystalline.

Cleavage: basal perfect, sectile scales, flexible but not elastic.

Fracture: practically controlled by cleavage.

Hardness: 1—1.5.

Streak: usually white. In dark-colored varieties streak is lighter than the color of the mineral.

Specific gravity: 2.7—2.8.

Occurrence: commonly only in spaces formed by alteration of other minerals. (See under *Crystallization* above.)

Associations: serpentine, talcose or chlorite schists and dolomite. Fibrous talc is usually pseudomorphic after enstatite and tremolite.

Alteration: not seen.

Tests: B.B. in closed tube, when intensely heated, most varieties yield water. In forceps whitens, exfoliates (opens out in plates), and very thin flakes fuse to a white enamel. Moistened with cobalt nitrate solution and heated, turns pale pinkish-red. Not decomposed by acids. Has a greasy feeling.

EPIDOTE: A hydrous silicate of calcium, aluminum and iron, $H_2O.4CaO.3(Al,Fe)_2O_3.6SiO_2$. (Al:Fe varies from 6:1 to 3:2.)

Color: yellowish-green to brownish-green, greenish-black, etc.

Luster: vitreous, inclining to pearly or resinous on cleavage.

Diaphaneity: transparent to opaque.

Crystallization: monoclinic; usually prismatic.

Cleavage: basal perfect, pinacoidal imperfect.

Fracture: uneven. Brittle.

Hardness: 6—7.

Streak: uncolored to grayish.

Specific gravity: 3.25—3.5.

Occurrence: commonly in slender prisms, needles and irregular grains, generally occupying space formed by decay of minerals.

Associations: quartz, actinolite, feldspar, chlorite, serpentine, etc.

Rocks: altered and metamorphic rocks, especially those rich in lime, whether igneous or sedimentary. Rock called epidosite consists of quartz and epidote.

Alteration: not observed.

Tests: Intensely heated in closed tube gives water. B.B. fuses with swelling at 3.5 to dark brown or black mass, generally magnetic. With soda and borax reacts for iron. Partially decomposed by hydrochloric acid. The fused mineral is decomposed by hydrochloric acid, with separation of gelatinous silica. Decomposed by fusion with sodium and potassium carbonates.

KAOLINITE, KAOLIN, CHINA CLAY: A hydrous aluminum silicate, $2H_2O.Al_2O_3.2SiO_2$.

Color: white, grayish-white, yellowish, brownish, etc.

Luster: of masses, pearly to dull earthy; of scales, pearly.

Diaphaneity: transparent to translucent in scales; opaque in masses, and generally plastic and unctuous.

Crystallization: monoclinic; thin rhombic, rhombohedral or hexagonal scales, usually compact, friable or mealy mass showing no crystallization.

Cleavage: of crystals, one perfect. Plates are flexible, inelastic.

Hardness: 2—2.5.

Specific gravity: 2.6—2.63.

Occurrence: from decay of aluminous minerals, especially of feldspars. Scaly kaolin often forms beds in connection with iron ores in the Pennsylvanian rocks.

Alterations: very resistant.

Tests: In closed tube yields water. B.B. infusible. Moistened with cobalt solution and heated, gives blue color. Insoluble in acids.

Economic: See clays.

HALLOYSITE: A silicate of aluminum, probably $2H_2O.Al_2O_3.2SiO_2+$water; alumina, Al_2O_3, 36.9 per cent. Much like kaolinite, but contains more water and is amorphous.

Color: varies with purity, from white to bluish-gray, greenish, buff, reddish.

Luster: pearly to waxy, to dull and earthy when dry.

Diaphaneity: translucent to opaque.

Crystallization: amorphous.

Occurrence: It is a secondary mineral derived from the alteration of rocks rich in aluminum, such as granites, and occasionally as a residual product from aluminous limestones, etc. It is also found in veins and other forms of ore-bodies.

Associations: other minerals of the kaolinite group.

Tests: B.B. infusible. With cobalt nitrate solution gives a fine blue color (alumina). Decomposed by acids.

Uses: See section on clays.

B. SECONDARY MINERALS RESULTING MAINLY FROM SOLUTION AND REDEPOSITION IN SEAMS AND CAVITIES IN BASIC LAVAS.

ZEOLITES AND RELATED MINERALS

The zeolites are mainly secondary, hydrous silicates of aluminum, with sodium and calcium, rarely potassium, barium and strontium. In some other respects they are analogous to the feldspars and feldspathoids, from which they are commonly derived by the action of heated waters and steam. They occur in cavities, seams and veins, chiefly in the more basic igneous rocks of volcanic origin, such as basalt and diabase, but occasionally in syenites, granites, and other more acidic types. Owing to their mode of occurrence, they commonly show good crystal forms. They range in color from white to pink, yellow and red. Vitreous and pearly lusters predominate. The specific gravity runs from 2 to 2.4, and the hardness from 3.5 to 5.5. They fuse easily and, most of them, with a boiling action and much enlargement. They are soluble in hydrochloric acid. The more important zeolites are: heulandite, stilbite, chabazite, analcite, natrolite, scolecite, mesolite and thomsonite. Apophyllite and prehnite are not strictly zeolites, but will be included in this group.

HEULANDITE: A hydrous silicate of calcium and aluminum, $CaO.Al_2O_3.6SiO_2.5H_2O$.

Color: white to gray to pink, red and brown.

Luster: pearly on conchoidal and cleavage surfaces; other faces vitreous.

Diaphaneity: transparent to nearly opaque.

Crystallization: monoclinic; often tabular, and resembling orthorhombic forms.

Cleavage: clino-pinacoidal perfect.

Fracture: subconchoidal to uneven. Brittle.

Hardness: 3.5—4.

Streak: uncolored.

Specific gravity: 2.18—2.22.

Occurs: mainly in openings in basaltic rocks, with other zeolites.

Tests: Before the blowpipe whitens, crumbles, fuses quietly to translucent glass. Decomposed by hydrochloric acid.

Colorado localities: Anthracite Creek, Gunnison County; Como, Park County; Green Mountain, Jefferson County.

STILBITE, DESMINE: A hydrous silicate of sodium and calcium, $(Na_2Ca)O.Al_2O_3.6SiO_2.6H_2O$. Variable.

Color: white, sometimes yellow, pink and red.

Luster: pearly on clino-pinacoid and cleavage surfaces; other vitreous.

Diaphaneity: transparent to translucent.

Crystallization: monoclinic; thin tabular, forming sheaf-like bundles; also radiating and globular forms.

Cleavage: clino-pinacoidal perfect.

Fracture: uneven. Brittle.

Hardness: 3.5—4.

Streak: uncolored.

Specific gravity: 2.1—2.2.

Occurrence: chiefly in basalt, but also in acidic rocks and mineral veins.

Associations: other zeolites, calcite, and other secondary minerals.

Tests: Separates, swells, curves and fuses to white enamel at 2—2.5. Decomposed by hydrochloric acid.

Colorado localities: North Table Mountain, Golden, and various mines of Cripple Creek.

CHABAZITE: A hydrous silicate of calcium, sodium, aluminum, sometimes potassium, etc. Variable, but commonly $(Ca,Na_2)O.Al_2O_3.4SiO_2.6H_2O$.

Color: white to pink and flesh-red.

Luster: vitreous.

Diaphaneity: transparent to translucent.

Crystallization: hexagonal; rhombohedrons, approaching the cube in angles.

Cleavage: rhombohedral, distinct.

Fracture: uneven. Brittle.

Hardness: 4—5.

Streak: uncolored.

Specific gravity: 2.08—2.16.

Occurrence: crystals, crystal groups and amorphous masses in openings in basaltic rocks and syenite, gneiss and schist.

Associations: other zeolites and calcite.

Tests: Fuses with swelling to a vesicular glass. Decomposed by hydrochloric acid, with separation of slimy silica.

Colorado localities: Table Mountain, Golden.

ANALCITE: A hydrous silicate of sodium and aluminum, $Na_2O.Al_2O_3.4SiO_2.2H_2O$.

Color: colorless, white, grayish, greenish-yellow, reddish.

Luster: vitreous.

Diaphaneity: transparent to nearly opaque.

Crystallization: isometric; trapezohedrons and cubes modified by trapezohedrons.

Cleavage: cubic, poor.

Fracture: subconchoidal. Brittle.

Hardness: 5—5.5.

Streak: uncolored.

Specific gravity: 2.22—2.29.

Occurrence: It is generally a secondary mineral, though it is probably primary in a few basaltic rocks. As a secondary mineral it occurs in cavities and replacing nephelite, leucite and sodalite.

Tests: Yields water in closed tube; fuses at 2.5 to a colorless glass. Dissolved by hydrochloric acid, forming gelatinous silica.,

Colorado locations: Table Mountain, Golden; Grouse Mountain, near Cripple Creek; Uncompahgre Peak.

NATROLITE: A hydrous silicate of sodium and aluminum, $Na_2O.Al_2O_3.4SiO_2.2H_2O$.

Color: white to colorless, to gray, yellow and red.

Luster: vitreous to pearly.

Crystallization: orthorhombic; slender prismatic crystals, often in divergent or radiating fibrous bunches.

Cleavage: prismatic perfect, another fair.

Fracture: uneven. Brittle.

Hardness: 5—5.5.

Streak: uncolored.

Specific gravity: 2.2—2.25.

Occurrence: principally in cavities and seams in basic rocks, but occasionally in granite, syenite and gneiss.

Associations: other zeolites and secondary minerals.

Tests: Fuses quietly at 2 to a colorless glass. Gelatinzes with acids.

Colorado localities: Table Mountain, Golden, and Cripple Creek.

SCOLECITE: A hydrous silicate of calcium and aluminum, $CaO.Al_2O_3.3SiO_2.3H_2O$.

Color: white to yellowish-white.

Luster: vitreous; silky when fibrous.

Diaphaneity: transparent to almost opaque.

Crystallization: monoclinic; slender, prismatic crystals, often in divergent groups and in various twin forms, some of which resemble natrolite forms.

Cleavage: prismatic, good.

Fracture: uneven. Brittle.

Hardness: 5—5.5.

Streak: uncolored.

Specific gravity: 2.16—2.4.

Occurrence: in crystal, fibrous and nodular forms, chiefly in openings in basic rocks.

Associations: other zeolites, calcite, and other secondary minerals.

Tests: Fuses at 2 to white vesicular enamel. Gelatinizes readily with acids. Sometimes curls up like a worm, when heated in the blowpipe flame.

Colorado localities: Table Mountain, Golden; Italian Peak, Gunnison County.

MESOLITE is intermediate between natrolite and scolecite in composition. It occurs in acicular and capillary crystals, often grouped in divergent tufts and felted masses in cavities in basaltic rocks, as at Table Mountain, Golden. It is colorless to white, grayish and yellowish; has a good prismatic cleavage; is transparent to opaque. It is commonly the last mineral to form in the cavities. Before the blowpipe it swells, curls into wormlike forms, and fuses easily to a white, glassy enamel.

THOMSONITE: A hydrous silicate of sodium, calcium and aluminum, $(Na_2,Ca)O.Al_2O_3.2SiO_2.5/2H_2O$.

Color: snow-white to greenish and reddish.

Luster: vitreous to pearly.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; seldom in distinct crystals; commonly in rounded, radiating bunches, but sometimes compact.

Cleavage: pinacoidal, good.

Fracture: uneven to subconchoidal. Brittle.

Hardness: 5—5.5.

Streak: uncolored.

Specific gravity: 2.3—2.4.

Occurrence: in cavities and seams in basic rocks; sometimes replacing nephelite.

Associations: other zeolites and other secondary minerals.

Tests: Fuses at 2 to white enamel. Gelatinizes with hydrochloric acid.

Colorado localities: Table Mountain, Golden.

CEBOLLITE: A hydrous silicate of calcium and aluminum, $(SiO_4)_3.Ca_5.[Al(OH)_2]_2$ or $5CaO.Al_2O_3.3SiO_2.2H_2O$. Small amounts of sodium and magnesium replace a part of the calcium. It is an alteration product from melilite and probably belongs to the zeolite group. It is probably orthorhombic, but was found in compact masses of fibrous character. It has a hardness of 5, and a specific gravity of 2.96. It gelatinizes with acids and gives off water when heated in the closed tube.

Locality: near Cebolla Creek, Gunnison County.

CREEDITE: A white to colorless monoclinic mineral having the composition, $CaSO_4.2CaF_2.2Al(F,OH)_3.2H_2O$. The crystals are of stout prismatic habit, and show curved faces, a perfect cleavage, a hardness of 3.5, and a specific gravity of 2.73.

B.B. it swells up and finally fuses to a white enamel. Is slowly soluble in acid.

It occurs embedded in a kaolin-like mineral in the fluorite-barite vein near Wagon Wheel Gap, Colorado.

APOPHYLLITE: A hydrous silicate of potassium and calcium, $K_2O.8CaO.16SiO_2.16H_2O$. A small amount of fluorine is usually present.

Color: white to grayish, sometimes pink, yellow, red.

Luster: pearly on basal pinacoid, glassy on other faces.

Diaphaneity: transparent to nearly opaque.

Crystallization: tetragonal; square prisms, often modified by pyramids and basal pinacoids, sometimes tabular.

Cleavage: basal perfect, prismatic good.

Fracture: uneven. Brittle.

Hardness: 4.5—5.

Streak: uncolored.

Specific gravity: 2.3—2.4.

Occurrence: mainly in cavities in basaltic rocks.

Associations: zeolites, datolite, pectolite and calcite.

Tests: In closed tube separates in flakes, whitens, and yields acid water. In open tube, fused with salt of phosphorus, reacts for fluorine.

Colorado localities: Table Mountain, Golden; Hunts Peak, Fremont County; and San Luis Park.

PREHNITE: An acid orthosilicate of calcium and aluminum, $2CaO.Al_2O_3.3SiO_2.H_2O$.

Color: light green, oil-green, to white and gray.

Luster: vitreous to pearly on basal faces.

Diaphaneity: subtransparent to translucent.

Crystallization: orthorhombic; well-formed crystals are rare; they are usually tabular parallel to the base, but prismatic forms occur.

Cleavage: basal distinct.

Fracture: uneven, brittle.

Hardness: 6—6.5.

Streak: uncolored.

Specific gravity: 2.8—2.95.

Occurrence: chiefly in openings in basic igneous rocks, such as basalt, diabase and related types, but occasionally in granite, gneiss and syenite.

Associations: zeolites, datolite, pectolite, calcite and epidote.

Tests: In the closed tube yields water. Fuses and swells to a vesicular enamel or glass. Decomposed by hydrochloric acid, and forms gelatinous silica if previously fused.

Differences: from green quartz, beryl and chalcedony by easy fusion.

DATOLITE: A basic orthosilicate of boron and calcium, $2CaO.B_2O_3.2SiO_2.H_2O$; boron trioxide, B_2O_3, 21.8 per cent.

Color: white to gray, pale green, pink, yellow, red and olive-green.

Luster: vitreous to subresinous.

Diaphaneity: transparent to translucent, to opaque when massive.

Crystallization: monoclinic; commonly short prismatic; also botryoidal and globular, and massive fine-granular or cryptocrystalline.

Cleavage: none.

Fracture: conchoidal to uneven.

Tenacity: brittle.

Hardness: 5—5.5.

Streak: white.

Specific gravity: 2.9—3.

Occurrence: It occurs chiefly as a secondary mineral in basic rocks, with calcite, prehnite and zeolites.

Tests: In closed tube gives water. B.B. fuses easily with swelling to clear glass, coloring flame bright green. Gelatinizes with hydrochloric acid.

PECTOLITE: A metasilicate of sodium and calcium, commonly classed with the pyroxenes, but by some regarded as allied to the zeolites, $Na_2O.4CaO.6SiO_2.H_2O$.

Color: white to gray.

Luster: silky to subvitreous.

Diaphaneity: weakly translucent to opaque.

Crystallization: monoclinic; in close aggregates of acicular crystals, sometimes radiating.

Cleavage: two perfect—ortho-pinacoidal and basal.

Fracture: uneven. Brittle. Compact pectolite is very tough.

Hardness: 5.

Streak: uncolored.

Specific gravity: 2.68—2.78.

Occurrence: as a secondary mineral in seams and cavities of basic eruptive rocks, and occasionally in metamorphic rocks.

Associations: calcite, prehnite and zeolites.

Tests: In closed tube yields water. Fuses at 2 to white enamel. Partially decomposed by hydrochloric acid, with separation of gelatinous silica. Often gives out light when broken in the dark.

CALCITE is described elsewhere.

C. SECONDARY MINERALS RESULTING MAINLY FROM DYNAMIC METAMORPHISM.

GARNET: Orthosilicates of calcium and aluminum; magnesium and aluminum; iron and aluminum: calcium and iron; (calcium, magnesium) and iron; calcium and chromium.

Color: red, brown, yellow, white, green, black.

Luster: vitreous in crystals to resinous in the massive form.

Diaphaneity: transparent to translucent.

Crystallization: isometric; dodecahedrons and trapezohedrons are the commonest forms.

Cleavage: no true cleavage, but a parting is sometimes distinct.

Fracture: subconchoidal to uneven.

Hardness: 6.5—7.5.

Streak: white.

Specific gravity: 3.15—4.3, varying with the composition.

Occurrence: Perfect crystal forms are common, but much massive and granular garnet occurs in metamorphic rocks.

Associations: Garnet is found in company with almost all rock-making minerals.

Rocks: metamorphic rocks, especially schists and gneisses.

Alteration: Very resistant, but chlorite, serpentine, hornblende, epidote and feldspar are formed.

Tests: All the varieties mentioned below, except uvarovite, fuse at about 3—3.5. Uvarovite is almost infusible. Almandite yields a magnetic globule. Almost all varieties react for iron. Uvarovite reacts for chromium, as do many pyropes. All but uvarovite are decomposed by hydrochloric acid, and gelatinous silica is generally separated. Decomposed by fusion with sodium and potassium carbonates.

VARIETIES

A. GROSSULARITE, *Gooseberry Stone, Cinnamon Stone, Essonite, Hessonite,* are names applied to calcium-aluminum garnets having the general composition $3CaO.Al_2O_3.3SiO_2$. In color they range from white to pale green, amber-yellow, brownish-yellow and cinnamon-brown. Grossularite is especially characteristic of metamorphic, calcareous rocks, especially at the contact of igneous intrusions.

B. PYROPE, *Precious Garnet,* is a magnesium-aluminum garnet having the general composition $3MgO.Al_2O_3.3SiO_2$. The color ranges from deep red to nearly black. Flawless, transparent stones are much prized as gems. Pyrope, probably not so commonly secondary, is characteristic of basic magmas, rich in magnesium and iron, but very poor in alkalies.

C. ALMANDITE, *Almandine,* is an iron-aluminum garnet, $3FeO.Al_2O_3.3SiO_2$, varying in color from deep red to purplish-red, brownish-red. When transparent and of fine red color, it is prized as a gem. The coarser material is crushed for abrasive purposes. Almandite is characteristic of mica schists and metamorphic rocks rich in aluminum and iron. With smaragdite (thin foliated amphibole near actinolite in composition) it forms eclogite.

D. SPESSARTITE, *Spessartine,* is a manganese-aluminum garnet, $3MnO.Al_2O_3.3SiO_2$, varying in color from dark hyacinth-red to brownish-red, and sometimes tinged with violet. The finer stones are used as gems. Found in granite rocks and quartzites.

E. ANDRADITE, *Common Garnet, Black Garnet,* is a calcium-iron garnet, $3CaO.Fe_2O_3.3SiO_2$, of various colors and many varieties. Wine-colored andradite is called *Topazolite;* a green variety of brilliant luster is *Demantoid; Melanite* is black; *Jelletite* and *Aplome* are green; *Rothoffite* is yellowish-brown to brown, etc. The black variety occurs in nephelite- and leucite-bearing rocks and in contact metamorphic rock.

F. UVAROVITE, *Ouvarovite,* is a calcium-chromium garnet of emerald-green color, $3CaO.Cr_2O_3.3SiO_2$, but is not known in crystals large enough for gems. Belongs with chromite in serpentine and occasionally in granular limestone.

G. SCHORLOMITE is commonly included with garnets. Its composition is $3CaO.(Fe,Ti)_2O_3.3(Si,Ti)O_2$. The color is black.

SILLIMANITE, FIBROLITE: An aluminum silicate, $Al_2O_3.SiO_2$.

Color: white to gray to brown to greenish.

Luster: vitreous.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; long, slender crystals, rarely showing terminal faces.

Cleavage: one perfect.

Fracture: uneven.

Hardness: 6.7.

Streak: uncolored.

Specific gravity: 3.23.

Occurs: mainly in fine, needle-like crystals, in either parallel or radiating groups. Sometimes massive. Often penetrating quartz.

Associations: minerals of metamorphic rocks, such as quartz, feldspar, micas, garnet, corundum, etc.

Rocks: gneisses, schists and other metamorphic rocks derived from clays or clayey sediments.

Alteration: very resistant.

Tests: B.B. infusible alone. Decomposed on fusion with sodium and potassium carbonates and hydroxides. Not decomposed by acids. The powder moistened with cobalt solution and strongly heated gives blue color (alumina).

ANDALUSITE, CHIASTOLITE: A silicate of aluminum, $Al_2O_3.SiO_2$.

Color: gray, to white, to rose, to reddish-brown and olive-green.

Luster: vitreous to subvitreous.

Diaphaneity: translucent to opaque, rarely transparent.

Crystallization: orthorhombic; usually nearly square prismatic forms.

Cleavage: one good (prismatic), and one fair.

Fracture: subconchoidal to uneven. Brittle.

Hardness: 7.5.

Streak: uncolored.

Specific gravity: 3.16—3.2.

Occurrence: generally in crystals, sometimes massive and radiating.

Associations: micas, hornblende, aluminous minerals of the kaolin group.

Rocks: argillaceous schists, mica schists, slates and related rocks.

Alteration: very stable.

Tests: B.B. infusible. After intense heating the mass, moistened with cobalt nitrate solution and reheated, becomes blue. Decomposed by fusion with sodium and potassium hydroxides and by sodium carbonate. Not acted upon by acids.

CYANITE: A silicate of aluminum, $Al_2O_3.SiO_2$.

Color: commonly blue, becoming paler or white toward margins of crystal; also gray, greenish and black.

Luster: vitreous to pearly.

Diaphaneity: translucent to transparent.

Crystallization: triclinic, generally long-bladed to columnar crystals.

Cleavage: one very perfect, one less perfect crossing the first, and a parting.

Fracture: obscured by cleavages.

Hardness: 5—7.25, depending on the crystal face tested.

Streak: uncolored.

Specific gravity: 3.56—3.67.

Occurrence: See *Crystallization.*

Associations: micas, garnet, quartz, staurolite, corundum.

Rocks: gneisses and schists.

Alteration: very stable.

Tests: same as for andalusite.

VESUVIANITE, IDOCRASE: A calcium aluminum silicate of uncertain formula, possibly $H_4Ca_{12}(Al,Fe)_6Si_{10}O_{43}$.

Color: brown to greenish-brown and green; occasionally resin-colored, yellow and bluish.

Luster: vitreous to resinous.

Diaphaneity: translucent to opaque.

Crystallization: tetragonal; prisms and pyramids; also massive, granular and columnar.

Cleavage: poor; lamellar structure somewhat common.

Fracture: subconchoidal to uneven.

Tenacity: brittle.

Hardness: 6.5.

Streak: white.

Specific gravity: 3.35—3.45.

Occurrence: mainly in metamorphic rocks, such as altered limestones, schists, gneisses, and especially as a result of contact metamorphism.

Associations: garnet, diopside, actinolite, tremolite, wollastonite, epidote and serpentine.

Tests: B.B. swells and fuses at 3 to a greenish or brownish slag. Reacts for manganese. Partially decomposed by hydrochloric acid. After intense heating it is completely decomposed by hydrochloric acid.

Colorado localities: Many localities along the Front Range of Colorado, and elsewhere in the state.

IOLITE, CORDIERITE, DICHROITE: A silicate of aluminum, iron and magnesium, $(Mg, Fe)_4Al_8(OH)_2(Si_2O_7)_5$, or $4(Mg, Fe)O.4Al_2O_3.10SiO_2.H_2O$.

Color: various shades of blue—light or dark.

Luster: vitreous.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; short prismatic; imbedded grains, massive and compact.

Cleavage: one fair, two poor.

Fracture: subconchoidal. Brittle.

Hardness: 7—7.5.

Streak: white.

Specific gravity: 2.6—2.66.

Occurrence: in granite, gneiss and schist, and related rocks.

Associations: quartz, orthoclase or albite, hornblende, tourmaline, sillimanite, andalusite and garnet.

Tests: B.B. loses transparency and fuses at 5—5.5. Partially decomposed by acids. Decomposed by fusion with sodium and potassium carbonates.

Uses: occasionally cut as a gem.

Colorado localities: many areas of metamorphic rocks, in gneisses and schists.

CHONDRODITE: A fluo-silicate of magnesium, usually with iron replacing a part of the magnesium, $H_2Mg_{19}Si_8O_{34}F_4$, or $[Mg(F,OH)]_2Mg_3(SiO_4)_2$.

Color: light to dark yellow, pale yellow, deep garnet-red brownish-red and hyacinth-red.

Luster: vitreous.

Diaphaneity: transparent to translucent.

Crystallization: monoclinic crystals of varied habits, commonly equidimensional; also massive, compact, and imbedded grains.

Cleavage: one sometimes distinct.

Fracture: subconchoidal.

Tenacity: brittle.

Hardness: 6—6.5.

Streak: white to pale yellow.

Specific gravity: 3.1—3.2.

Occurrence: commonly in altered limestones.

Associations: spinel, chrysolite, biotite, pyroxenes, magnetite and calcite.

Tests: B.B. infusible. Some varieties blacken, and then burn white. Reacts for fluorine (etches the glass) in closed tube with potassium bisulphate. Gelatinizes with acids.

Alteration: It becomes hydrated and changes to serpentine and brucite.

HUMITE is similar to chondrodite, but contains five molecules of $MgSiO_4$ instead of three, and is orthorhombic.

CLINOHUMITE is like chondrodite, but contains seven molecules of $MgSiO_4$.

SCAPOLITE: A group of silicates of aluminum, with calcium and sodium in varying amounts. Chlorine is often present. The scapolite series, like the plagioclase series, consists of two primary members: Meionite ($4CaO.3Al_2O_3.6SiO_2$), and Marialite ($Na_4Al_3Si_9O_{24}Cl$); and intermediate members: Wernerite and Mizzonite, composed of the primaries in varying proportions.

Color: white to grayish-white to pink.

Luster: vitreous.

Diaphaneity: transparent to translucent.

Crystallization: tetragonal; prisms and pyramids are characteristic.

Cleavage: prismatic, fair, but often interrupted.

Fracture: conchoidal to subconchoidal. Brittle.

Hardness: 5—6.5.

Streak: uncolored.

Specific gravity: 2.5—2.8 (decreases from meionite to marialite).

Occurrence: Frequently shows one or more crystal boundaries, and often perfect crystals. It is often the result of alteration of plagioclase.

Associations: augite, hornblende, calcite, sanidine, garnet, apatite, titanite, zircon.

Rocks: The scapolites are most common in metamorphic rocks—such as crystalline limestones, crystalline schists and gneisses—but are also found in trachyte and other volcanic rocks.

Alteration: They alter to micas, calcite, epidote, talc, quartz, and aluminum minerals, such as kaolinite, diaspore, gibbsite, and other minerals.

Tests: B.B. fuses easily with swelling. All varieties are attacked by acids, but in varying degree, and one variety—Sarcolite—gelatinizes.

STAUROLITE: A hydrous silicate of aluminum and iron, $5Al_2O_3.2FeO.H_2O.4SiO_2$, with magnesium replacing more or less of the iron.

Color: reddish-brown, yellowish-brown to nearly black.

Luster: commonly slightly resinous, to dull vitreous.

Diaphaneity: translucent to opaque.

Crystallization: orthorhombic; commonly in flat prismatic crystals, twinned so as to form crosses.

Cleavage: one fair.

Fracture: subconchoidal. Brittle.

Hardness: 7—7.5.

Streak: generally uncolored, sometimes gray.

Specific gravity: 3.65—3.71.

Occurrence: See *Crystallization.*

Associations: micas, garnet, cyanite, tourmaline, sillimanite, quartz, hornblende.

Rocks: metamorphic rocks, such as schists, gneiss, argillite, slate and phyllite.

Alteration: rarely altered.

Tests: B.B. infusible, except those varieties containing magnesium, which fuse easily to a magnetic glass. With soda and borax reacts for iron. Sulphuric acid attacks, but does not completely decompose it.

WOLLASTONITE: A calcium silicate, $CaO.SiO_2$; lime, CaO, 48.3 per cent.

Color: white to gray, yellow, red and brown.

Luster: vitreous to pearly.

Diaphaneity: translucent to weakly transparent.

Crystallization: monoclinic, mainly in tabular forms (tabular spar); also massive, fibrous-massive with interlocking fibers.

Cleavage: two perfect.
Fracture: ragged.
Tenacity: brittle.
Hardness: 4.5—5.
Streak: white to gray.
Specific gravity: 2.8—2.9.
Occurrence: commonly in granular limestones, especially as a result of contact metamorphism.
Associations: garnets, pyroxenes, vesuvianite, etc.
Tests: Not changed in closed tube. Fuses easily on edges, and with soda forms a blebby glass, and swells and becomes infusible. Decomposed by hydrochloric acid.

IV. IMPORTANT MINERALS OF SEDIMENTARY ROCKS

QUARTZ is by far the most important mineral of sedimentary rocks. It forms practically all the vast body of sandstones, and is present in considerable amounts in most argillaceous rocks, and as an impurity in many limestones.

QUARTZ is described elsewhere.

CALCITE is next in importance to quartz. It is the mineral of limestones, and is present in many argillaceous rocks, such as calcareous shales and clays.

CALCITE, ICELAND SPAR, CALC SPAR: Calcium carbonate; the mineral of limestone, marble, chalk, etc.; $CaCO_3$.
Color: white to colorless; also shades of gray, pink, red, etc.
Luster: vitreous to subvitreous and earthy.
Diaphaneity: transparent to opaque.
Crystallization: hexagonal; remarkably varied. (See Dana, Textbook of Mineralogy, p. 354.)
Cleavage: perfect, parallel to the rhombohedron *r*, yielding rhombohedral blocks or plates.
Fracture: rarely seen, owing to the perfection of the cleavages.
Hardness: 3.
Streak: white to gray.
Specific gravity: 2.7.
Occurs: In igneous rocks it is generally in irregular grains, formed by the alteration of feldspars and other lime-bearing minerals. In sedimentary rocks it occurs in granular masses, fibrous and platy.

Association: In igneous rocks it is found with the minerals from which it is formed—the plagioclases, amphiboles and pyroxenes—and with other secondary minerals.

Rocks: altered rocks, particularly those containing or having contained plagioclase and the ferromagnesian minerals. Limestones, dolomitic limestones, chalk, travertine and marble are composed wholly or largely of calcite.

Alteration: mainly by solution.

Tests: B.B. infusible, but becomes alkaline. Colors flame reddish-yellow, especially when moistened with hydrochloric acid. Effervesces when acid is applied, yielding carbon dioxide.

The uses of calcite are discussed in the section on the "Economic Uses of Rock-Making Minerals."

GYPSUM: A hydrous calcium sulphate, $CaSO_4.2H_2O$.

Color: white to gray, pink, blue, brown, etc.

Luster: pearly.

Diaphaneity: crystals transparent, others translucent.

Crystallization: monoclinic; flat, tabular, prismatic, and lenticular forms. Twins common.

Cleavage: selenite and satin spar good, very easy in two directions.

Hardness: 1.5—2.

Specific gravity: 2.3.

Occurrence: beds, sheets, seams, etc., in sedimentary rocks, and occasionally in igneous.

1. Massive, showing no definite crystals.
2. Snowy gypsum and alabaster, white or light-colored, compact, and very fine-grained.
3. Radiated and plumose.
4. Satin spar or fibrous gypsum, white and delicately fibrous.
5. Selenite, transparent, in plates or crystals.

Alteration: chiefly by solution.

Tests: Heated in closed tube gives off water, and becomes dull and opaque. Fuses at 2.5 to 3, coloring the flame reddish-yellow. The crushed bead has an alkaline reaction. When fused with soda, the mass moistened and crushed on silver causes discoloration. Soluble in hydrochloric acid.

HALITE is described under sodium minerals.

ANHYDRITE: Anhydrous calcium sulphate, $CaSO_4$.

Color: white, gray, red, blue.

Luster: vitreous to pearly to greasy.

Diaphaneity: subtransparent to translucent.

Crystallization: orthorhombic; crystals not common.

Cleavage: pinacoidal; three, fair, yielding rectangular pieces.

Hardness: 3—3.5.

Specific gravity: 3.

Occurrence: very similar to gypsum.

Alteration: chiefly to gypsum, and by solution.

Tests: Does not yield water in the closed tube. Otherwise like gypsum.

DOLOMITE: A carbonate of calcium and magnesium, $(Ca,Mg)CO_3$. or $CaCO_3.MgCO_3$.

Color: white, gray, pink, brown, greenish-gray.

Luster: vitreous to pearly, sometimes satiny.

Diaphaneity: transparent to translucent.

Crystallization: hexagonal; rhombohedral with curved faces.

Cleavage: perfect rhombohedral.

Fracture: smooth and somewhat curved. Brittle.

Hardness: 3.5—4.

Streak: uncolored.

Specific gravity: 2.8—2.9.

Occurrence: In igneous rocks it is a secondary mineral derived from the alteration of minerals containing calcium and magnesium. In sedimentary rocks it is common in magnesian (or dolomitic) limestones and marbles, and in many shales. In metamorphic rocks derived from either igneous or sedimentary rocks containing calcium and magnesium.

Associations: altered plagioclase, pyroxenes, amphiboles, secondary calcite, gypsum, micas, and other minerals common to igneous and sedimentary rocks.

Rocks: See under *Occurrence* and *Associations*.

Alteration: mainly by solution.

Tests: B.B. behaves like calcite. The powder effervesces in warm acid, but very slowly, if at all, in cold acid. Fragments are not acted upon by cold acid.

ARAGONITE: Calcium carbonate, $CaCO_3$, with occasionally a little strontium, or lead, or zinc.

Color: colorless to white to gray, yellow, green and violet.

Luster: vitreous to resinous.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; sometimes prismatic, with rather flat domes and pyramids; frequently long and slender, with acute domes and pyramids. Complex twinned groups in rosette forms with re-entrant angles.

Cleavage: two distinct, one poor.

Fracture: weakly conchoidal to uneven.

Tenacity: brittle.

Hardness: 3.5—4.

Streak: uncolored.

Specific gravity: 2.93—2.95.

Occurrence: in simple crystals, often grouped and radiating; more commonly in compound (twinned) crystals and columnar masses. Sometimes massive, granular. Stalactites and stalagmites with finely radiating structure are common.

Associations: very commonly in beds of gypsum, and in iron ores, where it assumes a coralloid form, and is called flos-ferri. Often found in basic lavas, such as basalt. It is a common associate of copper and iron pyrites, galena and malachite.

ANKERITE (DOLOMITE, BROWN SPAR, PEARL SPAR IN PART): Carbonate of calcium, magnesium, iron and manganese, $CaCO_3.(Mg, Fe, Mn)CO_3$. The normal mineral is $2CaCO_3.MgCO_3.FeCO_3$.

Color: white to gray to reddish.

Luster: vitreous to pearly.

Diaphaneity: translucent to almost opaque.

Crystallization: rhombohedral; crystals, crystalline, massive, granular and compact. Resembles limestone.

Cleavage: rhombohedral, perfect.

Hardness: 3.5—4.

Streak: white to colorless.

Specific gravity: 2.95—3.1.

Occurrence: in crystals and granular masses with siderite, magnesite and other carbonates.

Tests: Like dolomite, but darkens and becomes magnetic on charcoal. Reacts with fluxes for iron and manganese. Effervesces in acids.

KAOLINITE and other minerals of this group are the important minerals, proper, of argillaceous rocks, but in many cases they form only a small percentage of the rock. The remainder is made up of fine grains of other minerals, and of rock grains.

ECONOMIC USES OF ROCK-MAKING MINERALS

QUARTZ: Finely crushed pure quartz is used to give body to wood-fillers, to give "tooth" and body to certain paints, and as an abrasive in various forms, such as scouring-soaps, polishing-powders. Crushed quartz is used in making sand-paper, sand belts, and in sand-blast apparatus. In pottery manufacture it decreases the shrinkage of the burning clay, and is used in many glazes. Ground and finely pulverized quartz is taking the place of pumice in filters, in tooth-powders and delicate abrasive materials. Quartz and quartzite in blocks are used as a filler in acid towers in the chemical industry, and as a flux in certain smelting processes, particularly copper. Quartz is fused and blown or molded into test-tubes, crucibles, dishes, and other articles for use where high temperatures are necessary, or sudden cooling is needed. Crushed quartz is used in making fire bricks.

CARBORUNDUM is a silicide of carbon, CSi, produced by fusing together in an electric furnace about 54 parts silica sand, 34 parts coke, 10 parts sawdust, and 2 parts salt. Its chief use is as an abrasive, but a certain amount is employed in the metallurgy of steel. Its hardness nearly equals that of the diamond. It is made into wheels, bars, slips, stones and paper for grinding and other abrasive purposes.

Axolite is a trade name for certain forms of carborundum.

MICAS: Muscovite is used extensively in the arts and commerce, phlogopite (amber mica) has a more limited use, and biotite is still less important. On the market mica is classed as "sheet mica" and "scrap mica." Sheet mica is used as an insulating material in electrical engineering, and for stove and furnace doors, lamp chimneys, miners' lamps, phonograph diaphrams, and novelties of various kinds. Scrap mica is manufactured into "composite mica," "micanite," "molded mica," and other built-up sheets which for many purposes take the place of natural sheets. A few of the uses to which mica is put in the electrical industry are: in dynamo commutators, insulators in lamp sockets, lightning-arresters, switch boxes, fuse blocks, handles of electricians' tools, lamp sockets (blocks), telegraph insulators, feedwire insulators. From scrap mica are manufactured fire-proof coverings and non-conductors of heat. Ground mica is used in the manufacture of fancy paints; as an absorbent for nitroglycerine in the manufacture of explosives; as an ingredient of lubricants for heavy machinery; as a luster-giving material in wallpaper manufacture; and in the manufacture of asphalt roofing.

Phlogopite is used for many of the same purposes as muscovite, especially where transparency and color are not important considerations. It is said to be a less perfect non-conductor of electricity than muscovite. It is used for the commutators of direct-current motors and dynamos.

Biotite is not much used in the industries.

Colorado localities: Muscovite is found in small quantities at many points in the pre-Cambrian areas of the state, almost always associated with quartz and feldspar in pegmatite dikes. A few deposits have been developed, but no important shipments have been made. Some of the more promising deposits are those of Larimer, Boulder and Mesa Counties.

FELDSPAR: The principal use of feldspar is in the manufacture of pottery, porcelain, glazed brick and electrical ware. It is finely pulverized, and mixed with both the body and the glaze—in the former to the extent of 10 to 35 per cent; in the latter, of 30 to 50 per cent. For these purposes it must be practically free from iron-bearing minerals and muscovite. It is also used as a flux to bind together emery and carborundum grains in the manufacture of wheels and other forms.

A small amount is used in the manufacture of opalescent glass, false teeth, scouring-soaps, poultry grit. Crushed feldspar is used to cover concrete and tarred surfaces, to give them the appearance of granite.

Experiments are under way to determine the value of pulverized potash feldspar as a fertilizer.

Crushed feldspar is used to some extent as an abrasive. Many attempts have been made to use orthoclase as a source of potash.

LAZURITE, LAPIS-LAZULI: The Persian Lapis-Lazuli has been proved to be a rock and not strictly a mineral. It consists of diopside, amphibole, muscovite, calcite and pyrite, together with lazurite proper. It was once prized as a blue pigment, ultramarine, but it has been replaced by an artificial compound having the same color and qualities. It is still highly prized for vases, mosaics and small ornaments.

ULTRAMARINE (artificial) is a pigment made of china clay, sodium carbonate or sulphate, carbon, sulphur, and sometimes siliceous matter. There are several colors of ultramarine, but only the blue and green are of commercial importance.

PYROXENES, AMPHIBOLES AND SERPENTINE

ASBESTOS, ASBESTUS: The name was originally applied to a fibrous amphibole, but under present (commercial) usage it includes four minerals: *True Asbestos, Anthophyllite, Fibrous Serpentine* (or *Chrysotile)*, and *Crocidolite.* All these fibrous minerals resist fire up to rather high temperatures, are more or less acid-proof, and good non-conductors of heat. Of these four minerals only true asbestos (amphibole asbestos) and fibrous serpentine or chrysotile (serpentine asbestos) are important. Both consist of easily separable fibers of variable length, though those of true asbestos are longer and weaker than those of chrysotile. The chrysotile asbestos is usually freer from impurities, and has a greater number of uses than true asbestos.

True asbestos is a metasilicate of calcium and magnesium, with varying amounts of iron, manganese, sodium and other alkalies. It varies from white to gray, yellowish and greenish. When fresh and unweathered it is easily separated into long, tough, elastic fibers, which may be spun and woven into cloth or matted into felt.

Fibrous serpentine (chrysotile) is a hydrated metasilicate of magnesium ($3MgO.2SiO_2.2H_2O$), usually containing a small amount of iron. The fibers are soft and silky, very smooth and even, and remarkably flexible. It is reduced to a white, wooly-looking mass by picking, beating or running between rolls. A large proportion of the "asbestos" of commerce is fibrous serpentine.

Occurrence: Amphibole asbestos occurs almost exclusively in the ancient eruptive and metamorphic rocks. Chrysotile, on the other hand, is commonly found in massive serpentine rocks derived from eruptive rocks rich in the magnesium-bearing silicates. It is generally in well-defined gash veins or in branching veins.

Uses: The manufacture of fireproof cloth for firemen's suits, theater curtains, and other uses where resistance to heat is necessary. It is much used in packing steam engines, and for heat insulation, cements, paints, and wall plaster. It finds many uses in chemical works and laboratories. The low-grade material, and the waste from mining and preparing the better material, are made into shingles, slates, boards, and other building materials. Many patented preparations composed of plaster of Paris, magnesite, dolomite, wood pulp, vegetable fiber, hair, diatomaceous earth, and like materials, with more or less asbestos, are sold for non-conducting coverings. Asbestos is used exclusively in electrical engineering where both insulation and resistance to high temperatures are required.

JADE, NEPHRITE is a tough, compact, fine-grained tremolite or actinolite, varying in color from white (tremolite) to dark green (actinolite). The name ''jade'' is also applied to various substances, from which ornaments and utensils have been made.

TREMOLITE, of fine color and free from flaws, has some value as a cheaper gem or ornamental stone.

DIOPSIDE is cut and polished as an ornamental stone.

SPODUMENE and RHODONITE are sometimes used as gems and ornamental stones. The spodumenes are known as *Hiddenite* and *Kunzite*.

ZIRCON

ZIRCON (ZrO_2) and zirconium carbide were formerly used to a considerable extent in the manufacture of incandescent lamps, but the metallic filament is decreasing this use. Zirconia is an excellent insulator for both heat and electricity. It is highly refractory and is made into crucibles. It is a suitable material for the walls and linings of electric furnaces. It is unaffected by gases, acids or alkalies, and is used for chemical ware. An alloy of zircon and iron, ferrozirconium, is used in the steel industry. Clear crystals of good color are cut for gems and are called ''hyacinths.'' Crushed zircon is used as an abrasive.

STAUROLITE: Symmetrically formed crystals of good color and free from flaws have been polished for gems or ornamental stones.

GARNET: In addition to the use as an abrasive and as a gem stone, garnets are cut for ''jewels'' in watches. It is also sometimes used as a fluxing material.

CALCITE: The use of calcium carbonate for limes and cements is discussed in the section on the ''Materials of Limes, Cements and

Plasters." Its use in the manufacture of salts of calcium is discussed under calcium.

ICELAND SPAR is a perfectly clear, transparent, flawless calcite, found in veins in basalt near Helgustadir in Iceland. It is used for optical purposes, especially in instruments for polarizing light.

WHITING is finely pulverized and floated chalk, or precipitated calcium carbonate. It is used to modify the shade of pigments and as a basis of whitewash.

PUTTY is whiting mixed with linseed oil.

GYPSUM: Common gypsum is ground and used as a fertilizer; as an adulterant for foods and other commercial materials; in the glass and porcelain industries; as a retarder in Portland cement; in the manufacture of paints, calcimines, crayons and paper. Calcined gypsum, plaster of Paris, is discussed under "Limes, Cements and Plasters."

ALABASTER is a fine, white, compact gypsum, used for small statues and other ornamental designs. The term is also used for a variety of calcite.

SELENITE is a colorless to pink, transparent variety in distinct crystals or foliated masses, showing perfect cleavage and frequently a fibrous fracture. It occurs separately in gypsiferous clays and shales, and also in seams and masses in ordinary gypsum.

SATIN SPAR, FIBROUS GYPSUM, is a fine, fibrous selenite, generally beautifully opalescent and translucent. It is used for the same purposes as common gypsum, and for ornamental forms.

PLASTER OF PARIS and other products of calcined gypsum are discussed in the section on "Materials for Limes, Cements and Plasters."

KAOLIN MINERALS

(SEE ALSO SECTION ON CLAYS.)

INDIANAITE is believed to be a variety of halloysite formed as a residual product from sedimentary rocks.

ALLOPHANE: A hydrous silicate of aluminum, $Al_2O_3.SiO_2.5H_2O$; alumina, Al_2O_3, 40.5 per cent.

Color: varies from white to gray, blue-gray, greenish, buff and brown, depending upon the impurities present.

Luster: vitreous to subvitreous and waxy.

Diaphaneity: translucent.

Crystallization: amorphous; mainly as crusts, and seams with mammilary surfaces.

Tenacity: very brittle.

Hardness: 3.

Streak: uncolored.

Specific gravity: 1.85—1.89.

Occurrence: It is derived from rocks rich in feldspars.

Tests: same as those of halloysite, but gelatinizes with hydrochloric acid.

Uses: See section on clays.

BENTONITE: A member of the kaolin group of minerals. A hydrous silicate of aluminum, perhaps nearly montmorillonite.

Color: light yellow to pale olive-green, changing to cream color on exposure.

Luster: dull, earthy to waxy.

Diaphaneity: opaque.

Crystallization: not known to crystallize.

Cleavage: none.

Fracture: often finely jointed in the deposit.

Tenacity: soft, soapy or unctuous; brittle when dry.

Hardness: very soft.

Streak: light gray to cream color.

Specific gravity: 2.13—2.18.

Occurs: as seams and beds from a few inches to several feet thick, mainly in the clays and shales of the Benton and Niobrara formations.

Associations: other clays, gypsum, sodium sulphate, etc.

Tests: Soapy feeling, high plasticity and great absorption property; clings strongly to the tongue, is very smooth and free from grit.

Economic: sizing for paper, absorbent in dynamite manufacture, retarder for hard (gypsum) plaster; adulterant in candies and drugs; a remedial dressing under the name of antiphlogistine.

Notes: It has very great absorbent properties, being capable of taking up three times its weight or seven times its volume of water.

Colorado localities: very small amounts have been reported from the Cretaceous formations in Colorado, but the reports have not been confirmed.

NON-METALLIC ECONOMIC MINERALS AND THEIR USES

ALUMINUM NON-METALLIC MINERALS

CORUNDUM: SAPPHIRE, RUBY, EMERY: Alumina, Al_2O_3; aluminum, 52.9 per cent.

Color: gray, yellowish, brownish, red, white, blue.

Luster: vitreous to pearly and adamantine.

Diaphaneity: transparent to translucent to opaque.

Crystallization: hexagonal, with pyramidal forms predominating; crystals often rough and rounded.

Cleavage: basal and rhombohedral often good; twinning often develops good partings.

Fracture: uneven to conchoidal.

Tenacity: brittle to tough.

Hardness: 9.

Streak: uncolored.

Specific gravity: 3.95—4.10.

Occurs: rough, irregular, crystal masses; also massive, granular, coarse or fine; usually in crystalline rocks, such as limestone, gneiss, granite, schist, slate, syenite.

Associations: chlorite, tourmaline, cyanite.

Tests: Dissolves slowly in borax and salt of phosphorus to clear glass—colorless when free from iron. Powder becomes blue after long heating with cobalt nitrate. Infusible and unaltered by soda.

Remarks: According to purity, luster, crystal form and transparency, the mineral is divided into: (a) *Sapphire* and *ruby* when pure and of fine color; *Sapphire* is blue, *Ruby* is red. Oriental *Topaz* is yellow, oriental *Emerald* green, and oriental *Amethyst* purple corundum. (b) *Corundum* includes the dark-colored, the opaque and weakly transparent and translucent, the massive and granular forms. (c) *Emery* includes granular corundum, particularly that containing magnetite and hematite.

Uses: Corundum and emery are pulverized or granulated and molded into abrading forms such as wheels, whetstones, slips, hones, oil stones. It is also sold in powder of various degrees of fineness and made into abrading papers for polishing, stone and gem-cutting and polishing, glass frosting and etching, and wood-working.

NATURAL ALUMS, ALUM CLAY, ALUM SHALE, ALUM SLATE

There are two groups of minerals which may be included in this class—the Alums proper and the Halotrichites. Of the first group the principal members are:

KALINITE, a potassium alum, $K_2SO_4.Al_2(SO_4)_3+24H_2O$.
TSCHERMIGITE, an ammonium alum, $(NH_4)_2SO_4.Al_2(SO_4)_3+24H_2O$.
MENDOZITE, a sodium alum, $Na_2SO_4.Al_2(SO_4)_3+24H_2O$.

To the second group belong:

PICKERINGITE, a magnesium alum, $MgSO_4.Al_2(SO_4)_3+22H_2O$.
HALOTRICHITE, an iron alum, $FeSO_4.Al_2(SO_4)_3+24H_2O$.
APJOHNITE, a manganese alum, $MnSO_4.Al_2(SO_4)_3+24H_2O$.

The members of the first group are isometric, while those of the second are either monoclinic or triclinic. They are commonly the result of the formation of sulphuric acid by the disintegration of sulphides—chiefly those of iron. The bases—sodium, potassium, ammonium, etc.—are derived from the rock containing or associated with the sulphides. Some of these minerals are deposited about volcanic and fumarolic vents. In such cases the sulphuric acid necessary for the formation of the sulphate is of volcanic or fumarolic origin.

They are so easily soluble that they may be looked for only in arid regions or in places sheltered from moisture. Some of these, and related sulphates, form in favorable places in dry weather, but disappear in rainy or moist weather. When pure and unweathered they are white, but impurities and weathering frequently give yellow, pink and green tints, especially to pickeringite and apjohnite. They are all transparent to translucent. All have silky to vitreous luster; all occur in acicular and fibrous crystals, frequently forming crusts, and occasionally masses of mealy-granular character. All have the characteristic alum taste, though varying in astringency.

Tests: Kalinite fuses readily with frothing, gives an intense blue with cobalt solution, and is soluble in sixteen to twenty times its weight of cold water, and in about its own weight of boiling water.

Tschermigite sublimes in the blowpipe flame. On charcoal it gives a coating of ammonium sulphate and a residue which gives a blue color with cobalt solution. With soda it gives fumes of ammonia.

Mendozite and Pickeringite behave as ordinary alum.

Halotrichite fuses readily, cracks open, and under intense heat gives sulphur fumes and leaves a brown residue. With soda and borax it reacts for iron.

Apjohnite gives the usual alum tests, and with soda on platinum yields the characteristic blue-green of manganese.

ALUM CLAY, *Alum Shale, Alum Slate*: These are commonly sandy clay rocks in which the disintegration of iron sulphides has developed sulphuric acid, which has reacted on the alumina and other constituents of the clay, forming alums. The name is also applied to clay rocks containing much readily disintegrated sulphide of iron. The clay is mined, crushed and exposed to the weather, and the sulphuric acid formed reacts on the alumina; or it is roasted to oxidize the sulphide to the sulphate form, and finally to set free sulphuric acid, which reacts with the alumina of the rock forming alum.

Uses: If found in large quantities and easily accessible, these minerals would take the place of artificial alums. Halotrichite occurs in large quantities along the Gila River in New Mexico.

Colorado localities: Kalinite occurs as an efflorescence at Turkey Creek and Mount Vernon in Jefferson County; at various points in the sedimentary rocks along Little Thompson Creek in Larimer County; at various points in the Cretaceous shales east of the Front Range—e. g., near Boulder, near Coal Creek, near Canon City, near Beulah. But it has not been reported in commercial quantities. *Pickeringite* has been found near Colorado City. *Halotrichite* has been reported from several coal mines in this state. It occurs on outcrops of the Laramie coal strata near Marshall, at White Rock, and elsewhere in Boulder County. It is found in the Elk Mountains in Pitkin County.

ALUNOGEN: A hydrous sulphate of aluminum, $Al_2(SO_4)_3+18H_2O$; aluminum 8.1, sulphur trioxide 36.0 per cent.

Color: white to yellow to reddish.

Luster: vitreous to silky and pearly.

Diaphaneity: translucent.

Crystallization: not known.
Cleavage: none.
Fracture: fibrous.
Tenacity: brittle.
Hardness: 1.5—2.
Streak: white.
Specific gravity: 1.6—1.8.
Occurs: chiefly as fibrous crusts and masses over surfaces and in seams of disintegrating aluminum-rich rocks acted upon by sulphuric acid.
Tests: Melts in its water of crystallization to an acid solution, but when dehydrated is infusible. Gives deep blue with cobalt nitrate. Easily soluble in water.
Remarks: It is commonly associated with other soluble sulphates, such as kalinite, mendozite, halotrichite, etc.
Colorado localities: Doughty Springs and Alum Gulch.

ALUMINITE, WEBSTERITE: A hydrous sulphate of aluminum, $Al_2(OH)_4SO_4$; aluminum 15.6 per cent.
Color: white.
Luster: dull, earthy.
Diaphaneity: opaque.
Crystallization: not known.
Cleavage: none.
Hardness: 1—2.
Streak: white.
Specific gravity: 1.66.
Occurs: rounded or irregular, chalk-like masses of peculiar harsh feeling.
Tests: Infusible. In closed tube yields water. With cobalt nitrate is deep blue. Easily soluble in acids.

BARIUM AND BARIUM MINERALS

USES: The metal barium is not used commercially, but many salts of barium are in use.

The hydroxide, $Ba(OH)_2$, is used in chemical analysis.

Barium chloride is used in the preparation of "permanent white," a barium pigment.

The chlorate is used for fireworks.

The sulphate (barite) is extensively used as a pigment, a base for precipitating lake colors, and to give body to pigments. It is also used as a sizing for papers and textile fabrics, and in the manufacture of rubber, asbestos, cement, poker chips, and in the tanning industry. Blanc fixe is pure barium sulphate obtained by precipitation from a solution of barium sulphide by means of sulphuric acid or salt cake. If salt cake is used, the sodium sulphide by-product is sold to tanners as a hair-remover. Blanc fixe is used as a pigment. Lithophone is a compound of barium sulphate and zinc sulphide produced by mixing solutions of zinc sulphate and barium sulphide ($ZnSO_4 + BaS = ZnS + BaSO_4$). It is used as a pigment in white enamel paints, and especially in the manufacture of linoleum and oilcloth.

Barium carbonate is used as a source of various barium salts, and in chemical analysis.

The nitrate is used for fireworks.

BARITE, BARYTES, HEAVY SPAR: Barium sulphate, $BaSO_4$.

Color: white to gray and blue; yellow to brown and red.

Luster: vitreous to almost resinous; tabular faces sometimes pearly.

Diaphaneity: transparent to opaque.

Crystallization: orthorhombic; tabular forms bounded by vertical or wedging faces; divergent groups and laminated groups are common.

Cleavage: two perfect and one indistinct; one of the perfect cleavages is parallel to the tabular faces, and the other at right angles to them.

Fracture: uneven, but modified by the cleavages. Massive barite breaks with a rather even granular surface.

Tenacity: brittle.

Hardness: 2.5—3.5.

Streak: white.

Specific gravity: 4.3—4.6.

Occurs: in crystal and granular masses as vein matter and gangue in ore-deposits; also in limestones, sandstones, and occasionally in veins in granitic rocks; also as nodules and masses in residual clays.

Associations: ores of lead, zinc, copper; less abundantly those of other metals; calcite, celestite and strontianite; numerous zeolites.

Rocks: more common in sedimentary rocks, such as sandstones and limestones, but also in igneous and metamorphic rocks.

Tests: B.B. decrepitates and fuses at 3, coloring flame pale yellowish-green. The fused mass gives alkaline reaction when crushed and moistened on test papers. Fused with soda, reacts for sulphur on silver; fused mass sinks into the coal. Insoluble in acids.

Colorado localities: sparingly in many parts of the state. A vein of considerable size occurs near Boulder.

WITHERITE: Barium carbonate, $BaCO_3$.

Color: white to gray and yellowish.

Luster: vitreous on crystal faces, subvitreous to resinous on fracture and cleavage surfaces.

Diaphaneity: translucent in crystals to opaque in massive forms.

Crystallization: orthorhombic; twinned always into forms resembling hexagonal pyramids.

Cleavage: one distinct and one rather poor.

Fracture: uneven.

Tenacity: brittle.

Hardness: 3—3.75.

Streak: white.

Specific gravity: 4.27—4.35.

Occurs: columnar and granular masses filling veins and seams in rocks, and sometimes as a gangue mineral, particularly with lead and silver ores. Not a common mineral.

Tests: B.B. fuses at 2, coloring flame yellowish-green. Fused mass crushed and moistened gives alkaline reaction on test papers; with soda on coal, fuses and soaks into coal. Soluble in hydrochloric acid. Sulphuric acid precipitates insoluble barium sulphate from the solution.

Remarks: Barite has two prominent cleavages and is insoluble in acids.

Uses: Used to a limited extent as a substitute for lime in plate-glass manufacture to add luster; chemical reagent once used in sugar-refining; used to neutralize the soluble sulphates in clays in manufacture of terra-cotta. The principal sources of witherite are Scotland and Wales.

BARYTOCALCITE: A carbonate of barium and calcium, $BaCO_3.CaCO_3$; barium carbonate 66.3 per cent, or baryta, BaO, 51.5 per cent. *Color*: white, grayish, greenish or yellowish. *Luster*: vitreous to resinous. *Diaphaneity*: transparent to translucent. *Crystallization*: monoclinic; prismatic crystals; also granular massive. *Cleavage*: one perfect and one fair. *Fracture*: uneven, brittle. *Hardness*: 4. *Specific gravity*: 3.64—3.66. *Tests*: B.B. colors flame yellowish-green (barium), fuses on thin edges, assuming pale-green color. The mass reacts alkaline. Soluble in dilute hydrochloric acid.

RADIUM is a metal of the alkali earth series closely related in all chemical properties to barium. The atomic weight is 226.5.

It is present in all minerals containing uranium and thorium. In most uranium minerals the ratio of radium to uranium present is constant, and about $\frac{32}{100,000,000}$ which is equivalent to 320 milligrams of radium to the ton of metallic uranium. It is present in practically all rocks and minerals, and the older rocks appear to contain more than the younger. It is present in many mineral waters and other springs.

Detection: The surest means of detecting the presence of radium is the electroscope. The electroscope consists of two compartments, in the upper of which a gold leaf is suspended in front of a reading microscope. The lower compartment receives the mineral or rock to be tested. By means of a rod of vulcanite the gold leaf is charged with electricity. This causes it to rise and stand out at an angle with the supporting rod. The electricity is slowly discharged through the air by what is called leakage. As a consequence the leaf slowly returns to the vertical position. The rate of this leakage is read on a graduated scale in the microscope. If a radioactive substance is placed in the lower chamber the rays given off will discharge the electricity more rapidly and the leaf will fall more rapidly. The rate of fall due to the presence of the radioactive substance as compared with that due to natural leakage is a measure of the radioactivity, or of the radium present.

Uses of Radium: The chief use of radium apart from its use in scientific investigation is in medical science.

The sources of Radium in Colorado:

1. The carnotite deposits of the western tier of counties, and small deposits of carnotite and related minerals in other counties.

2. The pitchblende of Gilpin County.

3. A considerable number of the mineral springs of the state are radioactive.

BERYLLIUM, GLUCINUM

USES: There are no commercial uses for the metal or its salts. Certain beryllium minerals are used as gems. Gadolinite is used as a source of yttria, erbia, etc.

BERYLLIUM MINERALS DESCRIBED ELSEWHERE

Beryl, Chrysoberyl, Gadolinite, Phenacite.

BORON AND BORON-BEARING MINERALS

USES: The element boron is not in commercial use.

Borax, sodium borate, $Na_2B_4O_7.10H_2O$, is one of the most generally used commercial salts. In metallurgy it is used as a flux, for refining, soldering and cleansing surfaces; in the pottery and enamel-ware industries it is used as a glazing salt. It is used in glass manufacture, and as a mordant in the textile industry. It is an important ingredient in soaps and toilet preparations. In the hat trade it is used as a stiffener. It is a solvent for shellac and a dryer in paints. Borax is much used in tanning and fur-dressing, and in preserving meats.

Boric or boracic acid, H_3BO_3, is used chiefly in the manufacture of borax, but also for glazes and enamels, as an antiseptic, and for preserving meats, fish and milk.

IMPORTANT BORON-BEARING MINERALS

BORAX, TINCAL: Borate of soda, $Na_2B_4O_7.10H_2O$ or $Na_2O.2B_2O_3.10H_2O$.

Color: white to grayish, greenish and bluish.

Luster: vitreous, becoming dull and earthy on exposure.

Diaphaneity: translucent to opaque.

Crystallization: monoclinic; in prismatic crystals, often of large size.

Cleavage: one perfect (pinacoidal) and one less perfect (prismatic).

Fracture: conchoidal. Rather brittle.

Hardness: 2—2.5.

Streak: white.

Specific gravity: 1.69—1.72.

Occurs: in crystalline and granular crusts over marshes, and in crystals and granular layers in the muds of marshes of Nevada and California. In solution in waters of these marshes and in Borax and other lakes.

Associations: anhydrite, gypsum, calcite, celestite, colemanite, hanksite, glauberite, halite, natron, trona, sulphur, niter, thenardite, and other related salts.

Rocks: sedimentary rocks of dry lake beds and marshes.

Tests: B.B. puffs up and fuses to transparent borax glass. Colors flame yellow, but when mixed with fluorite and potassium bisulphate the flame is bright green. Soluble in water. Moistened with sulphuric acid and covered with alcohol, the burning alcohol gives a green flame. Has a sweetish, alkaline taste.

Uses: a source of commercial borax.

BORACITE, STASSFURTITE: Borate of magnesium, $Mg_7Cl_2B_{16}O_{30}$ or $6MgO.MgCl_2.8B_2O_3$.

Color: white, to gray, to greenish and yellowish.

Luster: vitreous to adamantine.

Diaphaneity: weakly transparent to translucent.

Crystallization: isometric and tetrahedral in form, but orthorhombic and pseudo-isometric in molecular structure; cubes, tetrahedrons, octahedrons and dodecahedrons.

Cleavage: poor octahedral.

Fracture: conchoidal, uneven.

Tenacity: brittle.

Hardness: crystals 7; massive 4.5.

Streak: white.

Specific gravity: 2.9—3.

Occurs: as isolated crusts and masses, sometimes forming strata or bands of considerable thickness either in deposits of other salts or in sedimentary clays and sands, in alkali lake and marsh deposits. Stassfurtite forms columnar and granular masses resembling marble.

Associations: anhydrite, gypsum, rock salt, potassium salts, and other magnesium salts.

Tests: Fuses at 2 with intumescence to a white, pearly glass, coloring the flame green. Soluble in hydrochloric acid. With copper oxide on charcoal colors flame azure-blue. Heated with cobalt solution it gives deep pink color characteristic of magnesium.

Uses: an important source of borax.

Notes: Alteration sometimes produces plumose centers in the crystals. This feathery mass is known as *Parasite*.

COLEMANITE, PRICEITE, PANDERMITE: Calcium borate, $2CaO.3B_2O_3.5H_2O$.

Color: colorless to white, gray and yellowish.

Luster: dull-vitreous to vitreous, adamantine and brilliant; crystal surfaces become dull.

Diaphaneity: transparent to translucent and opaque.

Crystallization: monoclinic; usually short prismatic.

Cleavage: one very perfect and one fair.

Fracture: Subconchoidal to flat, with fairly even surface.

Tenacity: brittle.

Hardness: 4—4.5.

Specific gravity: 2.42.

Occurs: crystals and crystalline groups, loose chalky masses and crust-like plates, and cleavable and granular masses, sometimes in well-defined beds of considerable thickness, interstratified with sedimentary clays, deposited in saline lakes and marshes.

Associations: other boron minerals, such as borax (tincal), ulexite (boronatrocalcite), boracite (stassfurtite), priceite and pandermite; rock salt, thenardite, hanksite, gypsum, and many others characteristic of salt and alkali lakes and marshes.

Tests: B.B. fuses easily, but imperfectly, with fracturing and exfoliation, coloring the flame green; readily soluble in hot hydrochloric acid, with separation of boric acid on cooling.

Economic: the chief source of borax in America.

Notes: It might be looked for in the alkaline lake and marsh areas of Colorado.

Priceite and *Pandermite* may be regarded as varieties of colemanite. The former occurs in loosely compact, friable, chalky masses; the latter in firm, compact nodules.

ULEXITE, BORONATROCALCITE: A borate of sodium and calcium, $Na_2O.2CaO.5B_2O_3.16H_2O$ (probably).

Color: white.

Luster: silky.

Diaphaneity: translucent.

Crystallization: fine, needle-like or fibrous.

Cleavage: none observed.

Tenacity: brittle.

Hardness: 1.

Specific gravity: 1.65.

Occurrence and associations: in dry lakes, alkali marshes with gypsum, rock salt, borax, glauberite, colemanite and related salts.

Tests: Yields water in closed tube. B.B. fuses at 1 to clear glass, coloring flame deep yellow. Moistened with sulphuric acid, the flame becomes momentarily green. Fused with acid potassium sulphate and fluorite, colors flame bright green. Weakly soluble in hot water. Soluble in acids. The water solution is alkaline.

Economic: A source of borax.

SASSOLITE, SASSOLIN: Natural boracic acid, H_3BO_3 or $B_2O_3.3H_2O$.

Color: white or yellowish.

Luster: pearly.

Diaphaneity: translucent.

Crystallization: triclinic; small, tabular or scale-like, crystals and scaly flakes.

Tenacity: brittle.

Hardness: 1.

Streak: white.

Specific gravity: 1.43.

Occurs: In steam jets from volcanoes, where it collects as a frost-like crust around vents, or is carried in the condensed water. Found in waters of Clear Lake, California, and in the borax deposits.

Tests: B.B. fuses easily, with swelling, to a clear, colorless glass, but colors the flame yellowish-green. Yields water in closed tube. Soluble in water.

Economic: a source of borax, formerly more important than at present.

BORON-BEARING MINERALS OF LESS IMPORTANCE, AND DESCRIBED ELSEWHERE: Datolite, Axinite, Tourmaline.

BROMINE, AND SOURCES OF BROMINE

USES: The chief use of bromine is in the manufacture of the bromides of potassium, sodium and ammonium, much used in medicine and photography. It is used in the color industry, particularly in preparing coal-tar dyes. It is prepared for use as a disinfectant by causing it to be absorbed into diatom earth. It is sold as "bromum solidificatum." Good diatom earth will absorb 75 per cent of its weight of bromine. Bromine is used to some extent in gold extraction instead of chlorine.

Sources: The commonest bromine-bearing minerals are Embolite, Bromyrite and Iodobromite, but practically all the bromine of commerce comes from brines used in salt manufacture and from sea-weed. At the Stassfurt refineries the mother-liquor from salt-refining contains 15 to 35 per cent bromine. Certain brines of Michigan, Ohio, West Virginia and Pennsylvania contain bromine in paying quantities, and the American production comes almost entirely from these states. Stassfurt is the largest producer of bromine.

CALCIUM AND CALCIUM MINERALS

USES: The metal calcium has no commercial uses, but certain compounds are much used.

Lime, CaO, is discussed elsewhere.

Calcium hydrate, slacked lime, $Ca(OH)_2$, is now prepared in large quantities and shipped in air-tight barrels for immediate use in mortar.

Chloride of lime, bleaching powder, is produced by the action of chlorine on calcium hydrate. It is extensively used as a bleaching agent and disinfectant.

Calcium bisulphite is used in the manufacture of wood pulp and in the purification of sugar.

Calcium sulphate, gypsum, is discussed elsewhere.

Calcium nitrate is now manufactured by an electrical process, using the nitrogen of the air. It is used with lime as a fertilizer.

Calcium phosphate: See apatite and phosphate rock.

Calcium carbide is much used for the production of acetylene for lighting purposes.

Calcium carbonate, limestone, calcite, is the most important calcium mineral and is the basal material for most of the calcium salts in use.

Calcium cyanide is used as a fertilizer.

IMPORTANT SOURCES OF CALCIUM COMPOUNDS

Most of the important calcium compounds—such as quick-lime, plaster of Paris, hydraulic lime and cements are derived from limestone, marble, dolomite and gypsum, which are regarded as rocks. They are described and their uses are discussed elsewhere.

THE MOST IMPORTANT CALCIUM-BEARING MINERALS ARE: Calcite, Dolomite, Aragonite, Gypsum, Anhydrite, Anorthite, Wollastonite, Colemanite, and Apatite, all of which are described elsewhere.

CARBON AND HYDROCARBON SERIES OF MINERALS AND ROCKS

The element carbon occurs native in the diamond, carbonite and graphite. It is the important element in coals, the solid and semi-solid hydrocarbons, amber, fossil resins, petroleum, and natural gas. While these are not true minerals, it seems best to discuss them under this general head and include them with the minerals. The uses will be discussed as the substances are described. They may be grouped as:

- Graphite, Diamond.
- Fuels and Illuminants:
  - Peat, Coal, Coke, and Other Products of Coal.
  - Petroleum and Its Products.
  - Natural Gas.
- Semi-solid and Solid Hydrocarbons.
- Amber and Fossil Resin.

GRAPHITE, PLUMBAGO, BLACK LEAD: Carbon; often contains iron oxide, clay and other impurities.

Color: crystals steel-gray to lustrous black; earthy forms are grayish-black, often iron-stained.

Luster: crystals metallic; massive and granular forms are commonly earthy and dull.

Diaphaneity: opaque.

Crystallization: hexagonal, rhombohedral; in six-sided tabular crystals.

Cleavage: one perfect.

Fracture: laminæ are flexible and inelastic.

Tenacity: easily separated or broken.

Hardness: 1—2.

Streak: same as color, black.

Specific gravity: 2.09—2.23.

Occurs: mainly in flaky or foliated or granular columnar and earthy masses in seams or beds in schists, crystalline limestones and granites; not uncommon as result of alteration in clay rocks; sometimes in clay rocks.

Tests: B.B. infusible; but burns at very high temperatures, as does diamond; insoluble in acids; very soft; has smooth, greasy feeling.

Uses: Graphite has many uses in commerce, such as: the manufacture of "lead" pencils, lubricants, paints for protection of metal surfaces, crucibles for metallurgical and chemical processes, stove polish; surfacing foundry molds; glazing; electrotyping; steam-piping; filler for dry batteries; protective surfacing against moisture on gunpowder, tea leaves, coffee beans; anodes and electrodes for the manufacture of alkalies, bleaching powder and electro-metallurgy.

Notes: Molybdenite gives a greenish-black streak, and when fused with soda reacts for sulphur. Artificial graphite is made from anthracite by means of the electric current.

Colorado localities: Turret, Chaffee County.

DIAMOND, CARBONADO, BORT: Crystallized carbon.

Diamond, of gem quality, is described in the section on Gem Minerals and Semi-precious Stones.

CARBONADO, Black Diamond, is a variety of diamond of black or grayish black color, and adamantine to resinous luster. It occurs in crystalline masses grading into true crystals, and is usually impure. The cleavage is very imperfect or lacking. It is used as an abrasive, especially for diamond drills and diamond saws.

BORT is low-grade diamonds of gray to black color, very poor cleavage, and confused crystalline structure. The hardness is greater than that of the crystals, but the specific gravity is lower. Fragments of crystals, and very imperfect crystals are also included under this name. Bort is used for the same purposes as carbonado.

FUELS AND ILLUMINANTS.

The principal mineral fuels are: coals, peat, petroleum and natural gas.

From coal are produced: coke, coal gas, water gas, and producer gas. Peat, lignite and the poorer grades of coal are sometimes placed under pressure and molded into briquettes for the purpose of increasing their density, improving their heating qualities and making them more conveniently usable. In a few places lighting and fuel gases are made from peat.

The refining of petroleum yields a great variety of products used for lighting, heating and the production of power. Of these the more widely used are: gasoline, naphtha, kerosene, power distillate, kerosene distillate, petroleum distillate, motor spirit and gas oil. Kerosene is more commonly used for lighting, but is also used for heat and power. Naphtha is used mainly for fuel, but has several other uses. The various distillates mentioned, and motor spirit are used for generating power. Gas oil is used for the manufacture of lighting and fuel gas. Residues of various kinds are used for fuel under various names, and for gas production. The final product of the distillation process is a coke having a high fuel value.

Natural gas, coal gas and water gas are used for heating, lighting and generating power. Producer gas is used largely as a source of energy in gas engines, but also as a fuel.

PEAT, COAL, COKE, AND OTHER PRODUCTS OF COAL

If we were obliged to depend upon the forests for fuel, our present industries would be impossible. At the present rate of forest depletion, and allowing for the present rate of regrowth, the forests of the country would last less than one hundred years. If to the present consumption of wood we add that which would be necessary if we had no coal, the forests would last but twenty or thirty years. But Nature anticipated man's needs, and ages ago, before there was a human being to use the fuel, she stored up the vast forest growths in the splendid coal seams with which the earth is so richly provided. In great marshy areas, covered with shallow water, rich vegetation grew year after year, age after age; and as the trees, ferns and other plants died and fell, they were covered with water, and thus preserved from complete decay, until masses of varying thickness were formed. These accumulations of vegetable matter were at least four times as thick as the coal seams made from them. A part of this transformation from vegetable tissue to mineral coal—that represented by the change from the growing plant to peat—took place under cover of water only. After a time the vegetable masses were buried by sand and clay, which have solidified into the rocks which now cover the coal. Little by little the change from tree and fern to solid coal took place under the immense weight of overlying rock. The heavier the rock cover, the more heat was developed, and the more heat, the more rapidly did the change take place. As a result, the more deeply the mass was buried, and the longer it was buried, the better the coal, other things being equal.

THE MATERIALS OF COAL

A careful examination of coals has shown the presence of a variety of vegetable matter. A very thin slice of bituminous coal examined under the microscope may show the woody structure so perfectly preserved that one might easily mistake the slice of coal for one of charred wood. A slice of splint or cannel coal examined in the same way may show the spores of fern-like plants and the pollen grains of flowering plants. Other coals show the presence of both fresh-water and marine plants.

Vegetable matter consists almost entirely of carbon, hydrogen and oxygen, in the proportions represented by the formula $C_6H_{10}O_5$. In the change from plant tissue to coal, carbon dioxide (CO_2), carbon monoxide (CO), water (H_2O), and marsh gas (CH_4) are given off in such quantities as to increase the proportion of carbon, and decrease that of hydrogen and oxygen. The presence of carbon dioxide, carbon monoxide and marsh gas in coal mines shows that the change is still in progress. Depending upon the advancement of the change, the mineralized vegetable matter is classed as: *Peat, Lignite, Black Lignite, Bituminous Coal, Anthracite* or *Hard Coal, Carbonite* or *Graphite*. In Colorado the coal forests grew at widely separated times and were buried under vastly different loads of rock. In some of the coal fields the growth of the mountains caused the folding of the rocks containing the coal. This compressed the vegetable matter, developed heat, and hastened the change. In some of them molten rock was forced, from deep within the earth, up between and into the coal seams. The heat thus supplied brought about, in a short time, changes which under ordinary conditions would have taken ages. In places where the heat was too great the coal was completely destroyed.

As a result of these varying conditions, the coals of Colorado represent almost every stage of change, from the lignites of the eastern parts of the eastern fields, to the hard coals or anthracites of Gunnison and Routt Counties, and the carbonite or natural coke found in the Trinidad field.

The common classification of coals includes the following:

(Carbonite or native coke, etc.)
Anthracite.
Semi-anthracite.

Semi-bituminous.
Bituminous.
Sub-bituminous.
Lignite.
(Peat).

The names ''semi-anthracite'' and ''semi-bituminous'' are confusing and should be replaced.

The following grouping is suggested:

(Carbonite, graphite, native coke.)
Superanthracite.
Anthracite.
Subanthracite.
Superbituminous.
Bituminous.
Sub-bituminous.
Lignite.
(Peat).

Many attempts have been made to base these subdivisions upon the chemical composition and physical properties of the coals, but none of the suggested bases of classification has been found entirely satisfactory. The data for these classifications depend upon: (1) the complete analysis of the coal; (2) the proximate analysis (an incomplete analysis which shows the percentages of fixed carbon, volatile hydrocarbons, ash and moisture); (3) the calorific power of the coal as determined by burning a sample. As a complete analysis is costly and time-consuming, a classification based upon it would be unsatisfactory. The proximate analysis and the calorific power are more easily obtained.

As more than 95 per cent of all coal mined is used for fuel, it is evident that any satisfactory commercial classification of coals must depend primarily upon their value for the production of heat. This depends upon two factors:

1. The percentage of the fuel constituents present in the coal.
2. The rate at which these fuel constituents may be converted into heat.

The first of these is known as the calorific power (heat-making power); the second is the calorific intensity (heat-making speed) of the coal.

The heat-units commonly used in measuring the calorific power of fuels, are the *British thermal unit*, B. T. U., and the *calory*. The

British thermal unit is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. The calory is the heat required to raise the temperature of one kilogram of water one degree centigrade.

The fuel constituents of a coal are the fixed carbon, the volatile hydrocarbons and the disposable hydrogen.

The *fixed carbon* is the carbon left behind in the form of coke when coal is heated to redness out of contact with air.

The *volatile hydrocarbons* are the gases composed of hydrogen and carbon which are driven off in the same process.

The *disposable hydrogen* is the excess of hydrogen above that required to unite with the oxygen of the coal to form water.

The calorific power of ordinary coals is roughly proportional to the percentage of fixed carbon they contain. But the available heat is decreased by the moisture present in the coal; for, as the coal burns, heat is consumed in evaporating the water it contains.

The calorific intensity (heat-producing speed), apart from the regulation of furnace drafts, depends very largely upon the volatile hydrocarbons. These cause the coal to flame and burn easily, but do not themselves yield much heat. Analyses show that fixed carbon and volatile hydrocarbons make up from 75 to 95 per cent of most coals. It is clear that if the fixed carbon is very high, the volatile hydrocarbons will be low, and the coal will yield a large amount of heat, but will burn slowly. On the other hand a coal low in fixed carbon and high in volatile matter will yield less heat, but will burn more rapidly.

Classifications of coals have been based upon:

1. The fuel ratio, or the ratio of fixed carbon to volatile hydrocarbons.

2. The fixed carbon.

3. The total carbon. This includes the fixed carbon and the carbon of the volatile hydrocarbons.

4. The total hydrogen.

5. The carbon-hydrogen ratio.

6. The calorific value (heating value) as determined by actual burning of the coal.

The following table shows that only the last of these gives the relative heating values of the coals:

	Fuel Ratio	Fixed Carbon	Total Carbon	Total Hydrogen	Carbon Hydrogen Ratio	Calorific Value in B. T. U.
West Virginia No. 10 ...	4.04	79.61	90.63	4.83	18.7	15,927
Arkansas No. 3.........	3.43	76.71	87.89	4.68	18.8	15,482
Pennsylvania No. 3 (anthracite)	10.22	88.82	90.73	3.39	26.7	14,906
Alabama No. 1	1.67	61.49	83.29	5.73	14.5	14,833
Colorado No. 1	1.16	45.96	65.71	6.18	10.6	11,525
North Dakota No. 1	0.87	38.30	61.43	6.08	10.1	11,465

It is only reasonable to expect that before long the buying and selling of coal will be placed upon a more scientific basis, and the price will be fixed by the determined heat-producing power of the coal.

Beginning at the bottom of the series, the main classes are described as follows:

PEAT is more or less carbonized vegetable matter, in which stems, leaves and roots of plants are still recognizable. In peat deposits there is generally a gradual transition from but slightly altered plants at the top, to a compact, earthy-looking substance, with little or no direct evidence of its plant origin, at the bottom. The color varies from a pale brownish-gray at the top, to deeper and deeper shades of brown and brownish-black. Sand and clay are generally present, though in some peats the amount is very small. When the more highly carbonized peat is subjected to very high pressure, it is converted into a coal-like mass. Peat is extensively used for fuel in European countries, but in America the abundance and cheapness of coal have prevented an important use of peat.

LIGNITE, Brown Coal: Under these names are included a rather wide range of coal-like substances forming practically a complete gradation from peat to true coals. In the lower grades the plant texture and structure are still apparent, but in the higher, mineralizing changes have almost completely destroyed these evidences of vegetable origin. The color ranges from yellowish-brown to jet-black, and the luster from dull and earthy to brilliant. The proportion of carbon is greater, and that of volatile matter less, than in peat. It occurs in seams between strata of sedimentary rocks, such as shale and sandstone.

BITUMINOUS COAL represents a more advanced stage of mineralization, and, as a consequence, the proportion of carbon is greater, while that of volatile matter is less, than in lignite. The color is black, the luster brilliant, especially on surfaces not corresponding to the planes of bedding. Its specific gravity ranges from 1.2 to 1.5. It occurs in seams, ranging from a few inches to forty or fifty feet in thickness, between sedimentary strata. In some places from ten to twenty seams alternate with rock strata.

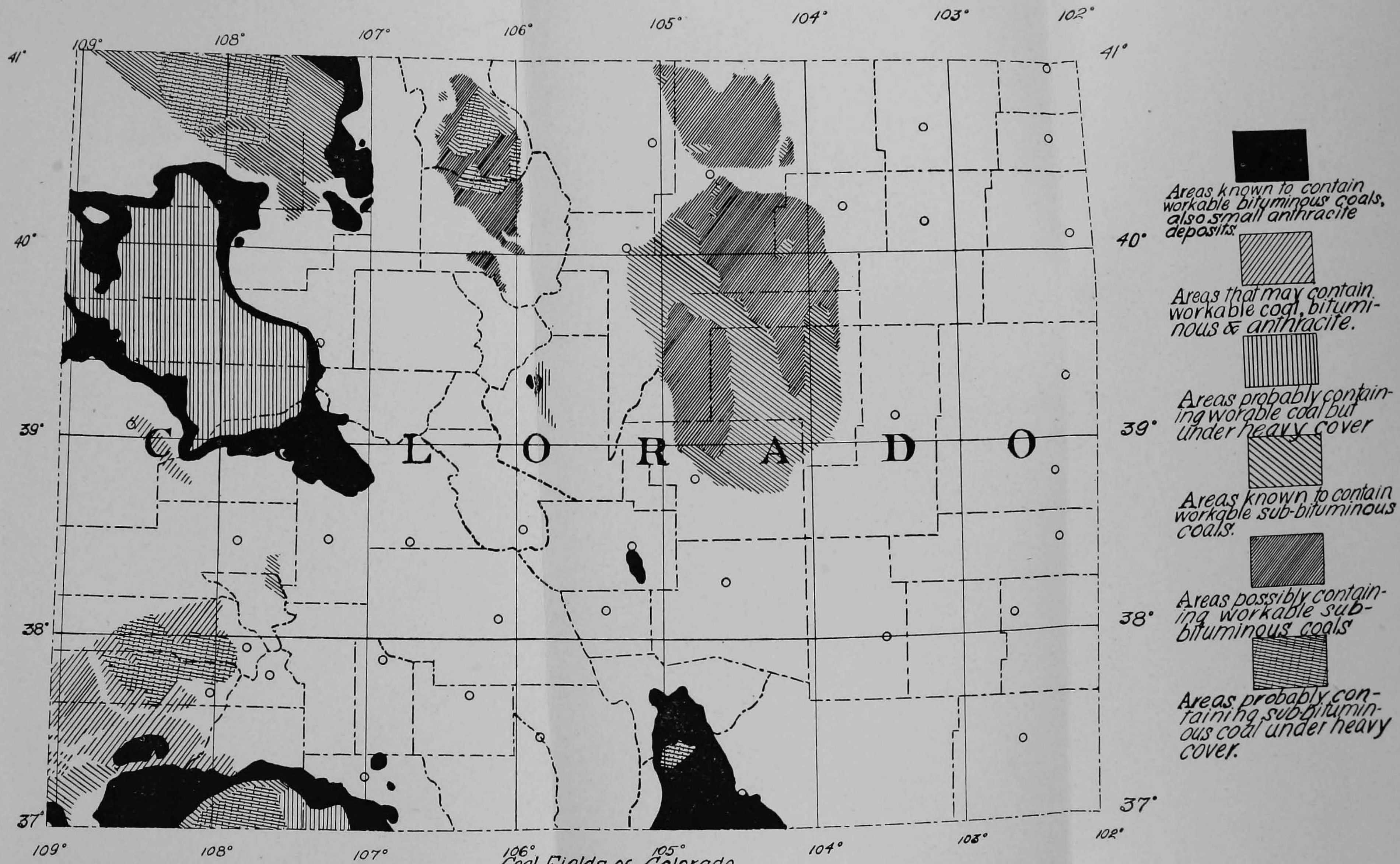
ANTHRACITE, Hard Coal: This is the hardest of the coals and has the highest carbon content. It is a dense, black, lustrous rock, breaking with a smooth, curved fracture, and having a specific gravity of 1.4 to 1.8. It does not burn so readily as the other coals, but gives out an intense heat. It occurs in the same way as bituminous coal, from which it is derived by more complete mineralization. The Pennsylvania anthracite occurs in the more folded part of the great Appalachian field, where the process of change was hastened by the compression and heat developed in the mountain-making movements. That of Colorado, New Mexico and Montana occurs in areas where igneous intrusions hastened the process of carbonization.

CARBONITE, Graphite, is more or less pure carbon. It results as an end product when the coal-making process goes on until only carbon remains. It is probably also derived from the solid or semi-solid hydrocarbons by extreme alteration. In schists, slates and limestones it is probably derived from plant and animal remains.

COAL IN COLORADO

The map following shows the main coal fields of Colorado and their extent. In estimated tonnage of coal Colorado is exceeded by only two states: North Dakota, with 500,000,000,000 tons (lignite), and Wyoming, with 424,000,000,000 tons. The surveyed and partially surveyed coal lands of Colorado, and the estimated tonnage, are as follows:

	Area (Square Miles)	Estimated Tonnage
Denver region	4,300	13,590,000,000
Durango field	1,900	21,428,000,000
North Park	500	453,000,000
Trinidad	1,080	24,462,000,000
Uinta region	6,000	271,810,000,000
Yampa field	3,700	39,639,000,000
Scattered fields	350	388,000,000
	17,130	371,770,000,000



Coal Fields of Colorado
U.S. Geological Survey

To these areas may be added others not yet surveyed, in both the eastern and the western parts of the state. The extent and tonnage of these fields are unknown, but they are probably not large. It must also be borne in mind that a large proportion of the coal lies beyond the depth to which profitable mining can be carried on at present, and it is more than probable that some of it can never be reached. At the present rate of consumption, Colorado's tonnage would supply the United States for about 750 years, or it would meet the present state consumption for 31,000 years. In 1873 Colorado mined only 70,000 tons of coal, whereas in 1911 she stood eighth among the coal-producing states, with an output of 12,000,000 tons. As yet the production comes mainly from the eastern fields, though the Grand River field in Gunnison County is a big producer. The following counties are the greatest producers:

Tons—	1910	1915
Las Animas	5,548,085	2,985,661
Huerfano	2,387,090	1,597,828
Boulder	802,769	971,360
Fremont	722,142	493,024
Gunnison	640,982	440,964
El Paso	336,780	297,881
Weld	322,896	439,860
Routt	258,452	846,459

The *Sub-bituminous Coals* of Colorado include those of the Denver region, the northern part of the Yampa field, a part of the Durango field, and the North Park and Como fields.

The *Bituminous Coals* are those of the Trinidad, the Canon City and Uinta fields, the southern part of the Yampa field, and the greater part of the Durango field.

Anthracite occurs in the southern part of the Yampa and the southern part of the Uinta fields.

Coking Coal occurs in parts of the Trinidad, Durango and Uinta fields.

The following table, compiled from United States Geological Survey Bulletins Nos. 341, 381, 415, 510, will give a fair idea of the calorific power of Colorado coals:

	B. T. U.
Denver region, 21 samples, average	10,901
Durango field, 5 samples ,average	13,350
Colorado Springs area, 11 samples, average	10,977
Canon City field, 12 samples, average	11,487
Trinidad field, 25 samples, average	12,726
Grand Mesa, 58 samples, average	12,167
Uinta and Yampa fields, 33 samples, average	12,144

(Uinta anthracite ranges about 14,400)

The average of 165 samples of bituminous and sub-bituminous coals is 11,993 B. T. U.

COKE

COKE is the product obtained when the volatile matter is driven from certain bituminous coals by strongly heating them in ovens or retorts from which the air is largely or completely excluded. It is essentially the "fixed carbon" of the coal, together with the ash and other incombustible matter contained in the coal. When a coking coal is thus heated, it becomes pasty, runs together, and forms a semi-liquid mass, which on cooling solidifies into a porous, columnar substance of dull steel-gray color and submetallic luster. In the coke-making process a ton of coal yields as follows:

Coke	1,100—1,500 lbs.
Ammonium sulphate or its equivalent	20—30 lbs.
Coal-tar	about 50—80 lbs.
Benzene	about 12—18 lbs.
Gas	8,000—12,000 cub. ft.
Hydrocyanic acid	1—3 lbs.

Cyanide salts are made from the hydrocyanic acid contained in the crude gas. The yield varies from 1 to 5 pounds per ton of coal.

The last five of these are called the by-products.

Coke ovens may be grouped under three general types: the beehive, the non-by-product retort oven, and the by-product retort oven. The beehive oven is a simple brick or stone chamber, provided with an opening in the top for charging and for the escape of gas, and one in the front wall for draft and drawing out the coke. This oven saves nothing but the coke. The non-by-product retort oven is designed to utilize the gas for coking purposes, and for the generation of steam or power through gas engines. So far as it goes, it is similar in construction to the by-product retort oven. This is a complex structure of steel and masonry, designed to save or utilize all the by-products. There are many different designs, but, in general, they consist of retorts for the coal, flues or fire-boxes through which the heat is applied; pipes, collecting troughs and condensers for handling and separating the volatile products. The tar is removed mainly in the first condensers, the ammonia in the second. The benzene is separated by a process called scrubbing, after which the residual gas, consisting mainly of hydrogen and marsh gas (methane), is piped back to the ovens as fuel.

The average cost of the beehive oven is about $300, while that of the by-product oven is $5,000. The advantages of the by-product oven may be stated as follows:

1. The average output per oven for 1910 was 1,762 tons, as compared with 376 tons for the beehive oven.

2. Fifteen per cent more coke. The average for 1910 was 1,498 pounds of coke per ton of coal, against 1,300 pounds for the beehive oven.

3. The net value of by-products per ton of coke is 22—25 cents.

4. The average total net cost of labor, maintenance of plant, depreciation of plant per ton of coke produced is 37 cents, as compared with 51 cents for the beehive oven. (This does not include the coal used.)

BY-PRODUCTS: In those parts of the country remote from the great markets and centers of population there is little or no demand for the by-products. As a result, nearly all the coke is made by the beehive process, and a large part of the tremendous waste is practically unavoidable. Even in the northeastern states the demand for coal-tar is unsteady. This is due to the backwardness of our chemical industry; for we import annually coal-tar products to the value of $10,000,000. Our farmers have not yet wakened to the immense value of ammonium sulphate as a fertilizer, especially in the growing of sugar beets. Again, the surplus gas would find little demand in Colorado on account of the limited development of manufacturing and the small population.

The Ammonium Sulphate: This is used largely as a fertilizer, but nearly all the other salts of ammonium on the market are made from the ammonium by-products of coke manufacture. In 1910 this by-product was valued at $3,860,000.

The Tar: The coal-tar by-product of 1910 was sold for $1,600,000. It would be impossible to give even a brief outline of the various and extensive industries based upon coal-tar as the raw material. In its raw state the tar is used for fuel, for gas manufacture, for weather-proof and chemical-proof paint, for the manufacture of roofing-felt and lamp-black, as a binder in briquetting slack coal, etc.

By distillation and other chemical processes coal-tar is made to yield hundreds of useful products, which may be grouped as follows:

1. Dye-stuffs (aniline salts), stains and other coloring materials—over 300 in number.
2. Perfumes and flavoring extracts—a long list.
3. Medicines and pharmaceutical preparations—such as carbolic acid, salicylic acid and its salts.
4. Disinfectants, antiseptics, anesthetics, etc.
5. Photographic preparations.
6. Creosote—used in various ways, but chiefly as a preservative for wood.
7. Picric acid is derived from phenol and benzene or benzol.

Benzene: The benzene is used mainly in carburetting water gas (increasing its illuminating power), but also for the manufacture of picric acid, used in making high explosives.

The Gas: A large portion of the gas driven from the coal is used to heat the ovens. The surplus finds ready demand for fuel, lighting and use in gas engines. In 1910, surplus gas amounting to 27,690,000,000 cubic feet, and valued at over $3,000,000, was sold for these purposes.

Cyanides: The cyanide salts are used mainly in the metallurgy of gold and silver.

Waste Heat: Until recently, few attempts have been made in this country to use the waste heat of coke ovens. In European countries this has been done successfully for some years. In Germany and Belgium the non-by-product retort oven is used extensively, and the surplus gas is burnt under steam boilers developing about fifteen horsepower per oven. The surplus gas from a modified form of beehive oven is used in the same way in the English coke industry. In America there are a few such plants in operation. One at Dawson, New Mexico, produces twenty horsepower per oven.

Careful estimates made by the United States Geological Survey show that the by-products wasted in the manufacture of coke are worth tens of millions of dollars annually.

COAL GAS: Coal is heated to a temperature of 1,700° to 1,850° F. in retorts. The volatile matter is driven off in the form of a complex gas or mixture of gases. This is subjected to cooling, condensing and scrubbing processes by which the tar, ammonia, sulphur gases, carbon dioxide, and other soluble and undesirable substances are removed. The purified gas from bituminous coal has roughly the following composition:

	Per Cent
Hydrogen	50
Marsh gas (methane)	30—35
Carbon monoxide	3—11
Unsaturated hydrocarbons, mainly ethylene and benzine	3—5
Traces of several other gases.	

It is the unsaturated hydrocarbons which give coal gas its value for illuminating purposes. The higher the percentage of these, the higher the candle-power of the gas.

Cannel coal yields a gas containing from 5 to 10 per cent of unsaturated hydrocarbons, and of proportionately higher illuminating power.

The yield of gas per ton of coal varies widely, but ranges from about 9,000 to 12,000 cubic feet.

WATER GAS: When steam is passed over red-hot coke or anthracite, the carbon of the coke or coal unites with the oxygen of the water, forming carbon monoxide, CO, and the hydrogen is separated. A small amount of carbon dioxide, CO_2, is also formed. This mixture of gases is known as "blue" water gas, and has approximately the composition:

	Per Cent
Hydrogen	52
Carbon monoxide	40
Carbon dioxide	4
Nitrogen	3
Other gases	1

This gas has very low lighting and heating powers. To increase these it is enriched (carburetted) by the addition of benzene vapor or oil gas, by which it may be given an illuminating power equal to that of coal gas from cannel coal, and a heating power approaching that of coal gas.

The composition of purified carburetted water gas is approximately:

	Per Cent
Hydrogen	40
Carbon monoxide	30
Saturated hydrocarbons	17
Unsaturated hydrocarbons	8
Nitrogen	5

PRODUCER GAS: When a limited supply of air is drawn or forced through a thick bed of highly heated coke, the supply of oxygen is not sufficient to cause complete combustion. The oxygen and carbon unite and form carbon monoxide, CO, and the nitrogen of the air is unchanged. The ideal result would be a mixture composed of 34.7 per cent of carbon monoxide and 65.3 per cent of nitrogen, but a small percentage of carbon dioxide is almost always present.

In practice, various sources of carbon are used, such as anthracite, bituminous and lignite coals, coke, charcoal and others. It is evident, therefore, that the composition of producer gas will vary with the source of the carbon. Again, water is introduced to keep down the temperature of the grates, and from this a certain amount of water gas will be formed. In some processes steam is mixed with the air as it enters the producer, and the result is a mixture of water gas and producer gas. The following table shows the general composition of producer gas:

	Per Cent
Carbon dioxide	5.0—15.0
Carbon monoxide	24.0—12.0
Hydrogen	9.0—28.0
Marsh gas	2.5— 0.0
Nitrogen	59.0—43.0

The calorific power is low, ranging from 80 to 160 B. T. U. per cubic foot, but the immense volume of gas produced more than compensates for this. One ton of coal yields from 140,000 to 160,000 cubic feet of producer gas.

PETROLEUM AND ITS PRODUCTS

PETROLEUM, COAL OIL (Rock Oil, Mineral Oil): The crude oil is an inflammable liquid, varying in color from a pale amber to rose-amber, red, brown, greenish-black and black, and in specific gravity from 0.76 (Apsheron, Russia) to 1.06 (Mexico). American oils commonly range between 0.80 and 0.98, though the extremes reach 0.77 and 1.00—the latter a Kansas oil. The inflammability depends largely upon the percentage of the lighter hydrocarbons which go to make up gasoline, naphtha, benzine and kerosene. When petroleum is slowly heated, these are driven off in gaseous form and accumulate at the top of the oil. A spark or small flame passed over the surface of the oil causes the gas to flash into flame. The lowest temperature at which this "flashing" occurs is known as the flashing point. In American oils the flashing-point is remarkably variable. An oil from Gaspe, Quebec, flashes below 0° F., while one from Alaska does not flash until 310° F. is reached.

The odor depends upon the composition. Some oils, especially those containing sulphur, have a disagreeable odor, while others have an aromatic, but not especially unpleasant, smell.

As to composition, petroleum is a mixture of various hydrocarbons, chiefly of the paraffin series (C_nH_{2n+2}), with a varying percentage of the olefin series (C_nH_{2n}), and the benzenes (C_nH_{2n-6}). Depending upon the character and proportion of the hydrocarbons composing petroleums, they are divided into "paraffin oils and asphaltic oils."

On this basis of classification, the oils of the United States would stand something as follows:

I. Paraffin base:
  - Appalachian field.
  - Ohio-Indiana field.
  - Illinois field mainly.
  - Michigan field.
  - Mid-continental field, some of Oklahoma oils and a few of Kansas.
  - Wyoming mainly.
  - Colorado.
  - Texas and Louisiana in small part.
  - Alaska.

II. Asphalt base:
  - Texas in large part.
  - Louisiana in large part.
  - Mid-continental field, most of Kansas, and a large proportion of Oklahoma oils.
  - California in large part.

III. Mixed asphalt and paraffin base:
  - Illinois in part, and locally elsewhere.

Occurrence and origin: It is found in reservoirs or "pools" formed of a porous rock—such as sandstone, sandy shale or limestone—and covered by an impervious cap rock, such as shale. These rocks are generally arched into an anticline or dome, though oil is found in a few places in synclinal folds and on monoclinals. It is so related to sedimentary rocks rich in organic remains that there seems to be little room for doubt that it is formed from the organic matter buried with them, by a process of distillation. A few scientists believe it is of inorganic origin. It is found in the rocks of various geological ages from the Ordovician to the later Tertiary.

Uses: By fractional distillation most petroleums, particularly the paraffin oils, may be broken up into oils of different specific gravity, adapted to different uses. Of these, gasoline, naphtha, benzine, and kerosene are best known, but heavier than these are many oils used for lubricating purposes, petroleum jellies, waxes, tars, and finally a residual coke used for fuel. It is said that over 300 petroleum products are on the market. The asphaltic oils, and those in which the asphaltic hydrocarbons are present in large percentage, are not so suitable for such fractional distillation, and are commonly used in the crude form for fuel. Most of the Texas, Louisiana and California oil is used for fuel.

Colorado localities: There are three oil fields in Colorado, all of which produce excellent paraffin oils. These are the Florence, the Boulder and the Rangely fields.

Refining: Crude petroleum is rarely, or never, fit for use as an illuminating oil, but some of the heavy paraffin oils of Wyoming and elsewhere have been found quite satisfactory for lubricating purposes. In the early days of petroleum-refining in America only the illuminating oil was considered of any value, and the whole process was crude and wasteful. Today the waste is but a very small percentage of the crude oil.

As crude oils vary widely in composition, the products of the refinery vary in kind and amount yielded. For example, the Pennsylvania oil yields much more kerosene than the Ohio. The Boulder crude yields more gasoline than the Florence.

Process: The crude oil is placed in a cylindrical still and heated. The vapors from the oil pass by pipes into condensers, where they are reduced to liquid. From the condensers the oil is classified, according to its specific gravity, as: naphtha, gasoline, kerosene, gas oil, spindle oil, light lubricating oil, heavy lubricating oil, cylinder oil, etc. After the oils come the paraffin waxes and tars, and finally a residue of porous oil coke used for fuel. This fractionation of the crude petroleum is but the first step in the refining. Every fraction must go through several processes for further purification. These may be illustrated by the treatment of the kerosene fraction. The oil is first put through a steam-heated still to remove the more inflammable part and render it less explosive. It is next piped to the agitator for treatment with sulphuric acid, to remove the unsaturated hydrocarbons, fatty and other acids, phenols, tarry products, and oxygen-containing bodies. The sulphuric acid is poured in, and compressed air is forced through the agitator to bring all parts of the oil into contact with the acid. When the agitation is completed, the acid, carrying the impurities, settles to the bottom. This mass, known as sludge, is drawn off, and the oil is washed with a solution of caustic soda to remove all traces of the sulphuric acid as well as petroleum acids, and acids formed by reactions between the sulphuric acid and the petroleum.

The oil is then placed in shallow tanks and washed with water to remove caustic soda and other impurities. Certain oils containing sulphur have to be treated with copper oxide to remove the sulphur. The sludge is treated to recover the sulphuric acid, and the residue is made into a land-fertilizer.

Before shipping the refined oil, it is tested to see at what temperature explosive vapors are formed from it. This is the ''flash'' test. Samples are also burned in standard lamps to test their candle-power and their mode of burning.

OIL SHALE, KEROSENE SHALE, TORBANITE, BITUMINOUS SHALE, are names applied to shaly rock containing sufficient petroleum or other hydrocarbons to make it profitable to distil it for the oil. Such shales are worked in Scotland, New South Wales and France. Before the production of petroleum became so great, oil-bearing shales were distilled to a limited extent in America. In Illinois and Tennessee a similar shale is distilled for the manufacture of mineral paint. The shale yields a dark oil and a black residue or pigment, both of which are used in paint manufacture.

Colorado Oil Shales: In the Green River formation of western Colorado and eastern Utah immense volumes of oil shale occur. In Colorado they are most extensively developed in Garfield and Rio Blanco counties where, in places, they attain an aggregate thickness exceeding 100 feet. Tests of these shales have yielded results which justify the hope that they may prove to be of great value as a source of oil and other hydrocarbon products.

NATURAL GAS

NATURAL GAS, MARSH GAS: Most of the natural gas of the United States is a mixture of several gases, among which marsh gas is by far the most important, forming from 80 to 98 per cent of the mixture. Nitrogen commonly ranges between 1 and 8 per cent, while hydrogen rarely reaches 2.5 per cent, and is sometimes absent. The first column in the table below is the average of seven analyses of natural gases from seven Ohio and Indiana localities; the second is the average of seven analyses of natural gases from seven Kansas localities; the third column gives the analysis of the natural gas in the Boulder field.

	I	II	III	IV
Hydrogen	1.73	0.00	2.40	0.80
Marsh gas	93.36	93.87	94.00	15.02
Olefiant gas	0.277	0.224	0.00	0.00
Carbon dioxide	0.254	0.444	0.00	0.00
Carbon monoxide	0.546	0.861	1.10	0.00
Oxygen	0.387	0.27	0.00	0.20
Nitrogen	3.28	4.03	2.50	71.89
Sulphuretted hydrogen	0.18	0.00	0.00	0.00
Inert residue	0.00	0.00	0.00	12.09

Analysis IV is that of a very peculiar "natural gas" found in boring for oil or gas at Dexter, Kansas. The well had an initial flow of 5,000,000 cubic feet per day. The gas would not burn alone, and was useless for either light or fuel. A very similar gas was found at Princeton, Illinois. A gas found at Middlesbro, England, contained 96.57 per cent nitrogen, 1.53 per cent oxygen and 1.90 per cent marsh gas.

Pure marsh gas is colorless and odorless, has a specific gravity of 0.55 that of air, and burns quietly, emitting a little light. When mixed with air in the proportion of 1 of gas to 5 of air, and up to 10 of gas to 13 of air, it becomes highly explosive. Natural gas from the wells is seldom entirely odorless, owing to the presence of olefiant gas, carbon monoxide, or sulphuretted hydrogen in greater or less amount. The Boulder gas smells of olefiant gas.

Occurrence: Natural gas is probably the product of the slow distillation of organic remains in sedimentary rocks. Marsh gas occurs in coal mines, where it forms the dangerous "fire damp" of the miners. It may be seen rising to the surface of stagnant pools whose bottoms are covered with decomposing plant matter.

As a commercial product it occurs in great reservoirs formed of porous rock—sandstone, sandy shale or limestone—capped or covered by an impervious rock, such as shale. These rocks are commonly arched so as to form a dome or an anticline, under which the gas is stored. It is found in rocks of various geological ages, from early Paleozoic to Tertiary, and occasionally, as in Iowa and Illinois, in glacial drift.

The yield of gas wells ranges from a few hundred cubic feet to thirty or forty million cubic feet per day.

Uses: (a) domestic—as fuel and for illuminating. (b) In the arts—as fuel for smelting, glass-making, cement-making, generating steam, and other forms of energy.

Colorado localities: It is produced in commercial quantity only in the Boulder oil and gas field.

HEAT VALUE OF FUELS

The following table, compiled from various reliable sources, shows approximately the calorific power of the principal fuels, in British thermal units. (The British thermal unit is the heat required to raise the temperature of one pound of water one degree Fahrenheit.) In stating the range of calorific power of the various fuels, the extremely high and the extremely low samples were not included.

Solid fuels, per pound:	Range-B. T. U.	Average
Coke, 60 samples	14,000—14,500	14,337
Anthracite, 21 samples	13,000—15,000	14,114
Bitmuinous coal, 38 samples	12,000—16,000	13,955
Sub-bituminous coal or Black lignite } 107 samples	9,000—14,000	11,899
Wood, various kinds, 15 samples	6,000—9,000	7,684
Peat, 24 samples	5,000—10,500	7,562
Liquid fuel, per pound:		
Petroleum (crude), 29 samples	18,000—21,000	19,611
Gaseous fuel, per cubic foot:		
Natural gas, 26 samples	850— 1,100	980
Coal gas, 15 samples	550— 700	620
Water gas, 23 samples	194— 402	326
Producer gas	....	150

The average calorific power of twenty-one samples of Pennsylvania anthracite was 14,114 B. T. U., while the average of twenty-eight samples of Pennsylvania bituminous coal was 14,983 B. T. U. From these and similar results it appears that the calorific power of the best bituminous coals is higher than that of anthracite.

SEMI-SOLID AND SOLID HYDROCARBONS

These substances are of variable and rather indefinite composition, and grade through pittasphalt and mineral tar (maltha) into the petroleums, from which, in all probability, most of them are residues derived by evaporation and oxidation. Their composition would thus depend upon that of the petroleum from which they came, and the conditions under which the changes took place. They are brown to black in color, have a silky to pitchy to waxy luster on fresh surfaces, and give a bituminous odor, especially when heated. Their hardness depends upon their composition and temperature. At ordinary summer temperatures some of them are soft and flow, while others retain their forms. When cold, they range in hardness from 1 to 3 or over, and break with a smooth, conchoidal fracture. The melting-point for the common forms is from 80° to 90° F., and most of them burn with sooty flames and disagreeable odors. Their specific gravities are mostly below 2.

Occurrence: Their modes of occurrence are as variable as are their physical properties. A lake-like body occurs on the island of Trinidad; veins, sheets and irregular bodies occur in Cuba, Canada and the United States. In Colorado, Utah, California, Kentucky, Arkansas, Oklahoma and elsewhere they are found filling the pores of sandstones and other rocks, as well as in veins with clean-cut walls. Shales and marls are sometimes charged with bituminous matter to such an extent as to burn readily.

As a natural result of their origin and mode of occurrence, it is plain that there must be gradations from one to another of these substances in composition, hardness, specific gravity and other properties. These facts, and the general likeness of the substances to one another have led to much overlapping and misuse of names, and to great confusion in the whole question of semi-solid and solid hydrocarbons. In the following pages only a few of the better known and more clearly defined members of the series are considered. Fuller descriptions and discussions will be found in works on petroleum, geology and mineralogy.

Some of these hydrocarbons, having fairly constant physical and chemical characters, have received specific names and are regarded as minerals. Such are: Albertite, Anthraxolite, Carbonite, or natural coke; Elaterite, Grahamite, Maltha, Manjak, Ozokerite, or mineral wax, or native paraffin; Uintaite or Gilsonite, Wurtzilite, Torbanite, Tabbyite, Nigrite.

Many similar products are obtained artificially in the distillation of coal, petroleum and hydrocarbon shale, and by the oxidation of petroleum. Some of these have received trade names, but are not regarded as *minerals* in the common usage of the term.

The word "Bitumen" is a term which has many different uses as applied to both natural and artificial products. The following definitions and descriptions of bitumen are taken from "American Petroleum Industry," by Bacon and Hamor.

BITUMEN—"A mixture of native or pyrogenous (*fire derived*) hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids or solids, and which are soluble in carbon disulphide." "A naturally occurring hydrocarbon complex often associated with a mineral matrix, insoluble in water, but largely soluble in carbon disulphide, benzole, etc." The first of these definitions covers practically the whole range of hydrocarbons.

> "It is usually limited to the plastic materials derived from natural asphalts, from oxidized petroleums, and from tars and pitches obtained from the destructive distillation of coal, mineral oil, etc. These materials may be broadly classified as natural asphalts, products of destructive distillation, and oxidized petroleum products. The natural asphalts range from the light fluid malthas, consisting of an asphaltic base and a light volatile hydrocarbon, to the hard, solid asphalts of the gilsonite type.
>
> "The tars and pitches may be obtained as the by-products in the manufacture of coal gas, water gas, oil gas, coke, or in any process where carbonaceous matter is burned with a limited supply of air.
>
> "The oxidized petroleums are obtained by blowing air through usually heavy petroleum residues at elevated temperatures. The changes produced are complex; but, in brief, part of the hydrogen present in the oil combines with the oxygen contained in the air and passes off as water vapor or steam, so that the per cent. of carbon is increased. The physical character of the oil is changed from a viscous liquid to a more or less rubber-like solid.
>
> "All of these materials vary to such an extent with their origin, treatment, method of refining, and final blending, that a classification based either on origin, method of production or subsequent treatment is impracticable. This is due in part to the fact that very few asphalts are used in their natural condition; they are treated in a variety of ways and blended with other materials to modify their original character. The harder asphalts are fluxed with petroleum oils so as to make them more plastic, while the more fluid are frequently heated so as to drive off the more volatile products. The artificial asphalts, obtained by oxidation of petroleum residues, may be modified in the same manner, while the tars and pitches vary with their source, method of production, and subsequent treatment."

ASPHALT, ASPHALTUM: These terms have had such varied uses that it is hard to give any satisfactory statement as to what asphalt or asphaltum really is. In general it may be said that there are three somewhat distinct uses of the word *asphalt*.

a. By some writers and scientists *asphalt* includes only the solid forms of the purer bitumens such as Albertite, Impsonite, Grahamite, Nigrite, Uintaite (gilsonite) and Wurzilite.

b. Industrially the word is made to include almost every compound of bitumen with foreign materials such as sand and limestone.

c. In the stricter scientific use of the term it includes any hard bitumen composed of saturated and unsaturated dicyclic, polycyclic or alicyclic hydrocarbons and their sulphur derivatives, which melts on the application of heat to a viscous liquid. A maltha may be converted into asphalt by heating or by other natural causes. Asphalts are distinguished by the large amount of sulphur they contain, and it is to its presence that many of the important characteristics and perhaps, in part, the origin of this form of bitumen is due. Richardson, Clifford, "On the Nature and Origin of Asphalt," Long Island City, New York, 1898.

ALBERTITE is a highly lustrous, black bitumen, having a hardness of nearly 3; a specific gravity of 1.08—1.11; a smooth, conchoidal fracture; a solubility of 4 per cent in ether and 30 per cent in oil of turpentine. When rubbed, it becomes electric and emits a bituminous odor. In a flame it swells up, gives off spurts of gas, and emits a bituminous odor. The principal known deposit is a vein in the Lower Carboniferous shales of Albert County, New Brunswick, where it has been mined to a depth of 1,500 feet. Small deposits are known in eastern Oklahoma and near Colton, Utah.

IMPSONITE is a variety of grahamite resembling albertite. It is a jet-black, almost lusterless mineral, closely resembling coal. It is extremely friable, and shows no sign of a conchoidal fracture. It burns readily, softens and cokes when heated in a glass tube, and when distilled in a retort yields a heavy distillate. It does not soften in boiling water, is almost insoluble in turpentine and only slightly soluble in alcohol, but 35 per cent soluble in carbon disulphide. It occurs in the Standley (Carboniferous) shale, Impson Valley, Oklahoma.

ANTHRAXOLITE is a lustrous, black, coal-like, combustible mineral of irregular composition, having a specific gravity of 2, a hardness between 3 and 4, and even, conchoidal fracture.

It occurs in veins in black slates near Sudbury, Ontario, and has been reported from other localities. Attempts have been made to use it for fuel.

CARBONITE or NATURAL COKE is a hydrocarbon of dull, lusterless, black color, and coke-like appearance. It has 79 to 82 per cent of fixed carbon, and burns like anthracite. It occurs in seams like coal in Chesterfield County, Virginia.

Natural coke occurs in the Raton and Anthracite and Crested Butte coal fields of Colorado, and is the result of the coking action of molten rock breaking through coal seams.

ELATERITE or MINERAL CAOUTCHOUC is a soft, easily compressible, elastic variety of bitumen, resembling pure India-rubber. It has a specific gravity of 0.905 to 1.233, is of a brown color, and contains 85 per cent carbon and 13 per cent hydrogen. A hydrocarbon locally called elaterite, but in some respects more closely resembling wurtzilite, is mined on Strawberry Creek and in tributary canyons in Utah, and shipped to Denver, St. Louis, and elsewhere to be manufactured into paint, roofing cement, roofing, and other commercial products. Elaterite has been reported from various points in Wyoming, and from Routt and Rio Blanco Counties in Colorado, but the presence of true elaterite in commercial quantity has not been proven.

GRAHAMITE is a lustrous, pitch-black, coal-like mineral, resembling albertite. It is completely soluble in chloroform and carbon disulphide, and nearly so in turpentine. Ether, naphtha and benzine partially dissolve it. It has a hardness of 2 and a specific gravity of 1.145. It occurs in veins in West Virginia, Oklahoma, Arkansas and Mexico, and is believed to be derived from petroleum.

MALTHA, PITTASPHALT, MINERAL TAR, is a viscid, semi-fluid, asphaltic bitumen, varying in liquidity, color and composition. It is a residual product from the evaporation of petroleum rising to the surface in springs and seepages. It is also obtained by the artificial distillation of asphaltic oils and bituminous rocks. The most important natural occurrence of Maltha in the United States is on the coast of California near Carpenteria.

OZOKERITE, MINERAL WAX, NATIVE PARAFFIN: This is a foliated, wax-like, paraffin hydrocarbon, varying in color from honey-yellow to greenish yellow, brown and jet-black, and in specific gravity from 0.845 to 0.97. The composition is C 85.7 per cent. H 14.3 per cent, which corresponds to C_nH_{2n}. The formula does not correspond to that of paraffin, but is like the olefin series. American ozokerite is jet-black. It is soft, plastic, greasy to the touch, and translucent when pure. It melts at 56°—63° C. (Redwood, p. 24, says 58°—100°), is completely soluble in petroleum, benzine, benzole, turpentine and carbon disulphide, and partially soluble in ether and alcohol. Promising deposits of ozokerite occur near Midway, Soldier Summit and Colton, on the Rio Grande Western in Utah. Small finds have been reported from Routt, Rio Blanco and Garfield Counties, Colorado, but no deposits of commercial importance have been found. The most important deposits are those of Galicia, where it occurs in sandstone and blue shale. When refined, it is used for candles, for adulterating beeswax, as a substitute for beeswax, and in the manufacture of ointments. A residual product, combined with rubber, is called okanite and is used for insulating electric cables.

FICHTELITE, HATCHETTITE, KÖNLITE and SCHEERERITE are simple hydrocarbons found in limited quantities in seams of peat and coal. They are closely related to ozokerite.

UINTAITE or GILSONITE is a lustrous, black bitumen, having a hardness of 2—2.5, and a specific gravity of 1.065 to 1.07. It breaks with a smooth, conchoidal fracture, and gives a dark-brown streak. It fuses in a candle flame; is plastic, but not adhesive, when moderately warm. It is a non-conductor of electricity, but becomes electric when rubbed. It is partially soluble in alcohol, more so in ether, and completely in chloroform and warm oil of turpentine.

Occurrence: It occurs in fairly well-defined fissure veins in the Tertiary sandstones of Uintah and Wasatch Counties, Utah, and adjacent parts of Colorado. A commercial deposit is being worked on Willow Creek in Middle Park.

MANJAK is a pure, lustrous, black, asphaltic uintaite, having a smooth, conchoidal fracture. It occurs in veins cutting the Tertiary oil rocks of Barbados, and is believed to be derived from petroleum. It is also found in Uvalde County, Texas. It is extremely brittle and friable, and when ground between the fingers yields a brown powder.

WURTZILITE is a brilliant, jet-black, compact hydrocarbon, resembling uintaite (gilsonite), but differing chemically and physically from it. In thin plates it is deep red. It cuts like horn, has a hardness of from 2 to 3, and a specific gravity of

1.0227. When cold it breaks with a smooth conchoidal fracture, but is tough and elastic when warm. In boiling water it softens, toughens and becomes elastic. In a flame it softens and melts, takes fire, and burns with a bright flame, giving a bituminous odor. It becomes electrical when rubbed. It resists the ordinary solvents of bitumens. It occurs in Carbon and Wasatch Counties, Utah. The principal deposits are those in several canyons tributary to Strawberry Creek.

TORBANITE, Boghead Cannel, Kerosene Shale, is a dense, black substance, rich in volatile hydrocarbons and closely resembling cannel coal. It breaks with a rather smooth, conchoidal fracture; has a dull, rubber-like luster, rarely bright; a hardness ranging from 1.5 to 3, and a specific gravity, when pure, of about 1. It occurs in irregular, detached bodies in shales of Carboniferous age in New South Wales and Scotland. Oil and gas are distilled from it. The best mineral yields from 150 to 160 gallons of crude oil, and about 20,000 cubic feet of illuminating gas per ton.

TABBYITE is an elastic, hard bitumen, probably related to both uintaite (gilsonite) and wurtzilite, and possibly to ozokerite.

NIGRITE is a brilliant jet-black hydrocarbon, having a cuboidal to massive structure, and a conchoidal to cuboidal fracture. It melts only when liberally fluxed with oil or gum.

ELATERITE and WURZILITE are by some writers regarded as very similar, if not identical; but this is probably an error due to local usage of names.

There are many other hydrocarbons related to these, but further study will be necessary to establish their right to distinct names.

ASPHALT ROCK, Bituminous Rock: Porous rocks, particularly sandstone and limestone, but also shales and marls, may be so charged with bituminous matter as to be available for paving and road-making by merely crushing them. Or they may be quarried and roasted to drive off the bituminous matter which is collected. The bituminous matter of such rocks varies in composition and physical character, just as do the different members of the bitumen series.

Colorado localities: Asphalt rock is found in Routt, Rio Blanco, Garfield and other western counties, and in Middle Park. Some of these rocks burn readily. Small deposits are known elsewhere in the state, as near Morrison. The percentage of asphalt varies with the porosity of the original rock and the degree of saturation. By weight, it occasionally reaches 15 per cent, and by volume 25 per cent.

The uses of the solid and semi-solid hydrocarbons may be grouped as follows:

1. Preservative:
   a. Low-grade varnishes and paints for preventing rust corrosion of iron and steel.
   b. Preventing decay of wooden paving-blocks, poles, posts, piles and ties; acid-proof linings for chemical tanks.
   c. Preserving and waterproofing masonry, paving-bricks, and other building materials.
2. Roofing, either with gravel and other mineral substances, or with fabrics of various kinds.
3. Paving, as a binder for crushed stone, gravel and sand, and as a surfacing material.
4. Lubricant for heavy machinery.
5. Substitute for rubber in hose, and similar commodities.
6. Binder in briquetting slack coal, peat and other substances.
7. Insulating materials for electrical engineering.
8. Ozokerite has special uses, which are mentioned under the description of that mineral.

AMBER AND FOSSIL RESIN

AMBER, SUCCINITE, FOSSIL RESIN: An organic substance in which the ratio for C, H, O is 10:16:1. Carbon 78.94 per cent, hydrogen 10.53 per cent, oxygen 10.53 per cent, and a trace of sulphur.

Crystallization: none.
Cleavage: none.
Fracture: conchoidal.
Hardness: 2—2.5.
Gravity: 1.05—1.096.
Luster: resinous.
Color: yellow to reddish, brownish and whitish, often clouded.
Streak: white.
Diaphaneity: transparent to translucent, and often clouded.
Occurrence: in rounded and irregular masses, plates and grains, associated with fossil wood, lignite and bituminous coal.

Rocks: those associated with coal.

Tests: Melts at 250°—300° F., and boils quietly after the fusion, giving off dense, white, aromatic fumes, which irritate the throat and nose. It becomes negatively electrified by friction.

Colorado localities: An amber-like fossil resin occurs in the black lignite of the Boulder coal field, and is reported from other areas.

True amber is a compound of several hydrocarbons, resulting from the mineralization of the resins of certain species of pines and other conifers. It is soluble to the extent of 10 to 12 per cent in alcohol, ether and chloroform, and contains from 3 to 8 per cent of succinic acid. It is found in many places, but the principal deposits are those of Samland on the Baltic coast, where it occurs in stratified sands containing lignite seams. A small quantity is found at Marthas Vineyard, and near Camden and Trenton, N. J. It occurs in pieces from the size of a pea to that of a cocoanut. Perfect amber in pieces weighing four ounces and over is worth from $15 to $20 per pound.

Uses: The manufacture of pipe-tips, cigar-holders, beads and cheap jewelry. The fragments and small pieces are compressed into "amberoid" and used for the same purposes, or are made into varnish.

RETINITE, GUM COPAL, BURMITE, CHEMAWINITE, GEDANITE, AMBRITE, and many other fossil resins bear more or less resemblance to true amber, and are used for similar purposes. Most of them contain little or no succinic acid.

CHLORINE AND ITS SOURCES

USES: Chlorine is much used in the bleaching industry, both alone and in compounds such as bleaching powder, chloride of lime. In the chlorination process of gold extraction, bleaching powder is the source of chlorine.

Hydrochloric acid is very extensively used in the industries.

The principal primary source of chlorine for all purposes is common salt, which is described under sodium.

FLUORINE AND FLUORSPAR

USES: The element has no uses in commerce. Hydrofluoric acid, HF, is used in etching glass. Fluorite, calcium fluoride and its uses are described below.

FLUORITE, **Fluorspar**: Calcium fluoride, CaF_2; fluorine 48.9 per cent.

Color: almost every color, from white (almost colorless), to deep red, deep green, etc.; but violet-blue and pale green are commonest.

Luster: vitreous to splendent.

Diaphaneity: transparent to almost opaque.

Crystallization: isometric; cubes, modified cubes and octahedrons; massive, granular, sometimes columnar and compact.

Cleavage: octahedral; perfect, in four directions.

Fracture: conchoidal to splintery.

Tenacity: brittle.

Hardness: 4.

Streak: white.

Specific gravity: 3.01—3.25.

Occurrence: Sometimes occurs in beds, more commonly in veins and seams in gneiss, arkose, slates, sandstone and limestone. It frequently forms the gangue of metallic minerals, such as tellurides of gold; lead, zinc and silver ores.

Associations: quartz, calcite, secondary feldspar, hematite, dolomite, millerite, sulphides of lead and zinc, stibnite, barite, and occasionally copper minerals.

Tests: In closed tube flies to pieces and glows. B.B. fuses, coloring flame red, forming an enamel which gives alkaline reaction when crushed and moistened on test paper. Fused with salt of phosphorus in open tube, etches the glass. With sulphuric acid gives hydrofluoric acid fumes, which etch glass.

Colorado localities: Cripple Creek, St. Peters Dome, Jamestown, Wagon Wheel Gap, San Juan, and many other localities.

Uses: The chief use of fluorspar is as a flux in the manufacture of basic open hearth steel. It is also used as a flux in blast furnaces. A considerable quantity is used in the manufacture of glass, enameled ware, sanitary ware; in the electrolytic refining of antimony and lead; the production of aluminum, and in the manufacture of hydrofluoric acid. For the steel industry it should be not less than 85 per cent pure, and for most of the other uses it should run 95 per cent calcium fluoride.

OTHER FLUORINE-BEARING MINERALS DESCRIBED ELSEWHERE: Amblygonite, Apatite, Lepidolite, Topaz.

LITHIUM AND LITHIUM MINERALS

LITHIUM, the lightest solid element known (specific gravity 0.59), is a soft, silvery-white alkali metal. It is very widely, but very sparingly, distributed in the rocks, sea and land waters, and in vegetation.

Uses: Lithium carbonate is used in the manufacture of storage batteries, artificial lithia waters, fireworks, and for medicinal purposes. The bromide is used in medicine and in photography. Other lithium salts are used in medicine. Lithia spring waters are held in high esteem for their medicinal properties.

MINERALS IMPORTANT AS SOURCES OF LITHIUM SALTS

LEPIDOLITE, Lithia Mica: Mainly a silicate of aluminum, potassium, lithium and flourine, $KLi(Al(OH,F)_2)Al(SiO)_3$; lithia about 5 per cent.

Color: lilac, rose-red, gray and violet and white.

Luster: pearly.

Diaphaneity: translucent.

Crystallization: monoclinic, but resembling hexagonal; short prismatic, with rounded terminations.

Cleavage: basal perfect.

Hardness: 2.5—4.

Streak: uncolored.

Specific gravity: 2.8—2.9.

Occurs: commonly massive, scaly-granular, and cleavable plates, in granitic rocks and gneisses.

Association: quartz, orthoclase, spodumene, cassiterite, amblygonite ($AlPO_4.LiF$), rubellite, muscovite.

Rocks: granite and gneiss, especially granite veins.

Alteration: like other micas.

Tests: In closed tube yields water and etches the glass slightly (fluorine). Fuses with swelling at 2.5 to a whitish glass, coloring the flame purplish-red (lithia). The fused mass gelatinizes with hydrochloric acid. Partly soluble in acids.

Uses: It has been mined as a source of lithium.

SPODUMENE: A silicate of aluminum and lithium, belonging to the pyroxene group, $Li_2O.Al_2O_3.4SiO_2$; silica 64.5 per cent, alumina 27.4 per cent, lithia 8.4 per cent. Sodium sometimes replaces a part of the lithium.

Color: white or ash-colored, grayish-white to greenish-white, yellowish-green to emerald, yellow and amethyst.

Luster: vitreous to pearly—cleavage surfaces usually pearly.

Diaphaneity: transparent to translucent.

Crystallization: monoclinic; often flattened to tabular prisms. with striated faces. Very large crystals are common.

Cleavage: one perfect cleavage parallel to the long axis, and a prominent parting separating the crystal into plates.

Fracture: uneven to subconchoidal.

Tenacity: brittle.

Hardness: 6.5—7.

Streak: white.

Specific gravity: 3.13—3.2.

Occurs: in granitic rocks, especially in pegmatite, greisen and related rocks, where vapors and gases have accompanied igneous activity.

Associations: beryl, tourmaline, garnet, tin ore, staurolite, columbite, tungsten ores, mica (especially lepidolite), triphylite-lithiophilite.

Tests: B.B. becomes opaque, swells, gives flame a deep, purple-red color, intensified by hydrochloric acid; fuses at 3.5 to clear white glass. Powdered and fused with fluorspar and potassium bisulphate, the "lithia red" is intense. Not acted on by acid.

Uses: Spodumene is an important source of lithium, and is mined in the Black Hills, where crystals 25 to 45 feet in length are found.

Beta-Spodumene is an altered form of spodumene in which one-half of the lithium is replaced by sodium. It is, in reality, a mixture of eucryptite and albite.

Cymatolite is formed as a second stage in the alteration of spodumene. It is a silky, fibrous mineral of pink to white color, and in reality a mixture of muscovite and albite.

Killinite is a third stage in the alteration of spodumene.

Hiddenite, an emerald-green spodumene, when clear and flawless brings a high price as a gem. Found at Hiddenite, North Carolina.

Kunzite is a beautiful pink or lilac variety, much prized as a gem.

TRIPHYLITE-LITHIOPHILITE: A phosphate of iron, manganese and lithium. (a) Triphylite is $LiFePO_4$ or $Li_3PO_4.Fe_3P_2O_8$, lithia 9.5 per cent. (b) Lithiophilite is $LiMnPO_4$ or $Li_3PO_4.Mn_3P_2O_8$, lithia 9.6 per cent.

Color: triphylite: gray, bluish-gray, greenish-gray; lithiophilite: pink, salmon, yellowish to brown. Surface often nearly black.

Luster: vitreous to resinous.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; coarse, massive, cleavable to compact, with rough faces. Crystals not common, but usually prismatic.

Cleavage: two nearly perfect at right angles, and one poor.

Fracture: uneven to subconchoidal.

Tenacity: brittle.

Hardness: 4.5—5.

Streak: grayish-white to almost colorless.

Specific gravity: 3.42—3.56.

Occurs: chiefly in regions where igneous intrusion has been accompanied by gaseous emanations.

Associations: other lithium minerals, rhodochrosite, uraninite, etc., in granitic rocks.

Tests: B.B. fuses very easily, giving the flame streaks of red (lithia) and a border of bluish-green (phosphorous). The color is intensified by moistening the powdered mineral with sulphuric acid and applying it to the flame with a platinum wire; reacts with fluxes for iron and manganese. Soluble in hydrochloric acid.

Uses: a source of lithium salts.

Remarks: Alters very easily by oxidation and hydration, forming a variety of minerals, such as Heterosite, Pseudotriplite, Alluaudite, etc.

AMBLYGONITE, HEBRONITE: A fluo-phosphate of aluminum and lithium, $Li(AlF)PO_4$ or $Li_2O.Al_2O_3.P_2O_5.F_2$.

It commonly contains soda and water.

Color: chalky-white to gray, greenish, bluish, yellowish and brownish.

Luster: dull vitreous to greasy. Some cleavage planes are pearly.

Diaphaneity: translucent to almost opaque.

Crystallization: triclinic. Crystals often large, but rarely perfect. Tabular forms result from twinning.

Cleavage: one perfect, one good and one fair. Cleavage results in columnar masses.

Fracture: uneven to slightly curved.

Tenacity: brittle.

Hardness: 6.

Streak: white.

Specific gravity: 3.01—3.09.

Associations: It occurs mainly in pegmatite or coarse granite with tourmaline of various colors, lepidolite, albite, spodumene, apatite, flourite, cassiterite, beryl, columbite, and tungsten minerals.

Tests: B.B. fuses easily, with swelling; becomes white and opaque when cool. Colors the flame deep red; moistened with sulphuric acid gives bluish-green flame. Powder is easily dissolved in sulphuric acid; less easily in hydrochloric.

Uses: It contains 10 per cent lithia, and is one of the principal sources of lithium salts.

Remarks: It somewhat resembles orthoclase. South Dakota and California are the chief producers of lithium-bearing minerals.

FREMONTITE: (formerly called Natramblygonite), is a hydrous phosphate of aluminum and sodium, $Na(AlOH)PO_4$ or $Na_2O.Al_2O_3.P_2O_5.H_2O$. A part of the sodium may be replaced by lithium, and a part of the hydroxyl by fluorine.

Color: greyish white to white.

Luster: vitreous.

Diaphaneity: translucent to opaque.

Crystallization: monoclinic; in thick tabular crystals.

Cleavage: basal and orthopinacoidal.

Fracture: uneven to slightly curved.

Tenacity: brittle.

Hardness: 5.5.

Streak: white.

Specific gravity: 3.05.

Occurrence: Colorado—mined near Canon City, Fremont County.

Tests: See amblygonite.

Uses: It contains a varying percentage of lithia up to 10 per cent, and is one of the principal sources of lithium.

Remarks: It resembles orthoclase.

Occurs: With other lithium-bearing minerals, apatite, fluorite and other rare element minerals.

PETALITE is a silicate of lithium and aluminum, $LiO_2.Al_2O_3.8SiO_2$, containing 4.9 per cent of lithium. It is a colorless to gray, transparent, vitreous mineral, having two good cleavages, a hardness of 6—6.5, and a specific gravity of 2.39—2.45. *Tests*: Heated gently, it gives a blue phosphorescent light. B.B. on coal becomes glassy and melts on thin edges, and gives the lithia red flame. Not acted on by acids.

MAGNESIUM AND MAGNESIUM MINERALS

Uses: The metal is used as a source of intense light for flash lights in photography, and in fireworks. It is a powerful reducing agent, and is used to some extent in separating the metals from certain refractory oxides.

The oxide, MgO, is used in medicine under the name *Magnesia usta*. It is also used as a separating agent in the Solvay process.

The sulphate, Epsom salt, is used in weighting or sizing cotton yarn and fabrics, and in dyeing. It has a limited use as a fertilizer, especially for clover hay. It is much used as medicine.

The hydrate is used in sugar-refining.

The chloride is used as a bleaching agent.

The carbonate (magnesite) is by far the most important magnesium compound, and is the principal source of the metal and the other compounds. Its uses are fully described under the mineral magnesite, below.

MINERALS IMPORTANT AS SOURCES OF MAGNESIUM AND MAGNESIUM COMPOUNDS

MAGNESITE: Magnesium carbonate, $MgCO_3$; magnesium oxide 47.6 per cent. Iron carbonate is a common impurity.

Color: white, to gray, to yellowish and brown.

Luster: vitreous to silky in fibrous varieties; sometimes dull, chalky.

Diaphaneity: transparent to opaque.

Crystallization: hexagonal rhombohedral; crystal forms are rare, but rhombohedrons and prismatic forms occur. Sometimes fibrous.

Cleavage: rhombohedral cleavage is perfect, giving cleavage blocks similar to those of calcite.

Fracture: flat conchoidal.

Tenacity: brittle.

Hardness: 3.5—4.5.

Streak: white.

Specific gravity: 3—3.12.

Occurs: veins and nodules in serpentine, serpentine marbles, talcose, and other rocks high in magnesium. The noted deposits of California are in serpentinized magnesium rock, where the mineral seems to be, in part at least, derived from the alteration of the serpentine, though some may have come directly from the original minerals of the rock. It is fine-grained, breaks with a smooth, conchoidal fracture, the surface of which resembles the broken edge of china. A little is in powdery form.

Associations: other magnesium minerals, such as serpentine, dolomite, talc, brucite, olivine, enstatite, etc.

Tests: B.B. infusible, but gives alkaline reaction on test papers after strong ignition; heated with cobalt nitrate turns pink; the powdered mineral effervesces in warm hydrochloric acid, but not in cold acid. The solution yields but little or no precipitate with sulphuric acid, whereas calcite and dolomite yield heavy precipitates.

Uses: The raw mineral is used in the manufacture of carbon dioxide. The calcined mineral, which is really the oxide magnesia, has many uses, the more important of which are: as a refractory lining for metallurgical furnaces, especially those used in making basic open hearth steel, and smelting copper. Cement kilns are frequently lined with calcined magnesite.

In the building trade it is used in making fireproof floors, partitions and roofs, wainscoting, staircases, doorways, window-casings; tile, drain pipe, tanks, trays, washtubs, moldings.

Miscellaneous uses are: in the manufacture of paper from wood pulp; as a lithographic stone, as a covering for steam pipes, as an adulterant for paints; ladles for molten metal, tuyeres for blast furnaces.

It is mixed with other substances into a plastic mass and used as a flooring for steel railway cars.

BRUCITE, Native Magnesia: Magnesium hydrate, $Mg(OH)_2$ or $MgO.H_2O$; magnesia 69.0 per cent.

Color: white, to gray, to blue or green, and sometimes pearly pink.

Luster: pearly to waxy and vitreous.

Diaphaneity: transparent to translucent.

Crystallization: rhombohedral; broad tabular forms; commonly foliated massive and fibrous. The folia are flexible and more or less elastic, much as in selenite.

Cleavage: basal almost perfect.

Tenacity: sectile.

Hardness: 2.5.

Specific gravity: 2.38—2.4.

Occurrence: in serpentine, magnesian limestone, and pseudomorphous after dolomite.

Tests: In closed tube gives water, becomes opaque and friable, and frequently turns ashy gray to brown, especially if manganese is present. B.B. infusible, glows and becomes alkaline to test paper; with cobalt solution gives pink color (magnesium). Soluble in acids.

EPSOMITE, Epsom Salt, Hair Salt: Sulphate of magnesium, $MgSO_4.7H_2O$; sulphur trioxide, 32.5 per cent, magnesia 16.3 per cent.

Color: white.

Luster: vitreous when unaltered; earthy and dull after exposure.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; prismatic and needle-like forms.

Cleavage: one perfect, one less perfect, and one poor. The first and last are parallel to the long axis of the prismatic crystals.

Fracture: conchoidal.

Tenacity: brittle.

Hardness: 2—2.5.

Streak: white.

Specific gravity: 1.75.

Taste: bitter, saline.

Occurs: a constituent of sea water and of many mineral waters. It frequently forms frost-like or fibrous coatings, hair salt, over mine and cave walls. It sometimes forms thin layers in gypsum deposits. The walls and floors of the dry parts of the limestone caves of Indiana, Kentucky and Tennessee are frequently covered with it. Large deposits occur in dry lake basins in Albany County, Wyoming.

Associations: many sodium, potassium and magnesium salts.

Tests: Very soluble in water, yielding a bitter saline solution. B.B. fuses and finally yields an infusible alkaline mass, which gives a pink color when fused with cobalt nitrate solution. Heated in closed tube yields much acid water.

Remarks: In many cases sulphuric acid resulting from the disintegration of pyrite reacts with the magnesium of the containing rock, forming epsomite.

Colorado localities: coal mines, mineral waters, certain alkali deposits, and alkali lakes.

BLÖDITE is a hydrous sulphate of magnesium and sodium, $MgSO_4.Na_2SO_4+H_2O$; magnesium sulphate 36.4 per cent, sodium sulphate 42.0 per cent. Occurs in short prismatic crystals, and massive, granular, compact. Has a faint saline and bitter taste.

MAGNESIUM-BEARING MINERALS DESCRIBED ELSEWHERE:

1. Possible sources of magnesium and its salts:
   Carnallite, Dolomite, Kainite, Picromerite (Schoenite).
2. Other magnesium minerals: Amphiboles, Biotite, the Chlorites, Chondrodite, Olivine, Phlogopite, Pyroxenes, Serpentine, Spinel, Talc.

NITROGEN AND NITROGEN COMPOUNDS

The greater part of the nitric acid of commerce is made from sodium nitrate, *Chili Saltpeter*.

Ammonia is obtained almost entirely as a by-product of coke-making and gas-making. The nitrates and ammonia compounds yield their nitrogen readily, and as a consequence are much used as fertilizers.

Explosives—such as gunpowder, gun cotton, dynamite and nitroglycerine—contain either nitric acid derivatives or niter. Others contain ammonium compounds.

The Nitrates Are Described Elsewhere. Sodium Niter or Chili Saltpeter and Saltpeter, potassium nitrate, are the only important nitrates commercially.

OXYGEN

The oxygen of commerce is derived mainly from the oxides of manganese and lead, and various nitrates and chlorates, and from the electrolysis of water.

The manganese oxides are described under manganese, and the lead oxides under lead.

PHOSPHORUS AND PHOSPHORUS MINERALS

USES: The element phosphorus has comparatively few uses in commerce. The most important is in the manufacture of matches. It is used as a vermin poison, and as a reagent in chemical laboratories. Salts of phosphorus have numerous uses in medicine.

By far the most important use of phosphorus is as a fertilizing agent in the form of superphosphates, made from apatite and phosphate rock.

THE IMPORTANT SOURCES OF PHOSPHORUS

APATITE: A phosphate of calcium, with fluorine or chlorine, or both. Fluor-apatite, $(CaF)Ca_4(PO_4)_3$ or $3Ca_3P_2O_8.CaF_2$; chlor-apatite $(CaCl)Ca_4(PO_4)_3$ or $3Ca_3P_2O_8.CaCl_2$. The fluor-apatite is much more common than the chlor-apatite.

Color: green, to bluish-green, to brown, to flesh-pink and yellow, sometimes violet and white.

Luster: vitreous, sometimes slightly resinous.

Diaphaneity: transparent, translucent to opaque.

Crystallization: hexagonal; prisms, terminated by pyramids and basal pinacoids.

Cleavage: rather poor basal, and still poorer prismatic.

Fracture: conchoidal to uneven. Brittle.

Hardness: 5; sometimes less in massive apatite.

Streak: white.

Specific gravity: 3.17—3.23.

Occurrence: in crystals and crystal grains in igneous rocks; massive granular, and in crystals in metamorphic rocks.

Association: It is found in igneous rocks of all kinds, and therefore with almost all rock-making minerals. It is a common mineral in metalliferous veins.

Rocks: in practically all kinds of igneous rocks; in metamorphic rocks, especially crystalline limestones, gneisses and schists; in pegmatites; in limestones and shales. It is one of the most widely distributed rock-making minerals, but is generally present in small quantity.

Alteration: a very stable mineral.

Uses: Large deposits occur in Canada and elsewhere, and are used for the manufacture of fertilizers and as a source of phosphorus.

Tests: B.B. fuses on thin edges at about 5, imparting reddish-yellow color to the flame; moistened with sulphuric acid and heated, colors flame bluish-green (phosphoric acid). Soluble in hydrochloric and nitric acids, yielding with sulphuric acid a precipitate of needles of calcium sulphate.

Colorado localities: Near Gypsum, in the dark andesites of Cripple Creek, and as an accessory mineral in igneous rocks in many parts of the state.

PHOSPHATE ROCK is described under rocks of organic origin.

SUPERPHOSPHATES: The normal phosphate of lime, $Ca_3(PO_4)_2$, as found in phosphate rock, bone ash, apatite, etc., is practically insoluble in water, and is therefore not available for plant food. To make it available to the plant, it is treated with sulphuric acid and converted into a soluble mass, known as superphosphate of lime, which consists of a mixture of the primary phosphate of lime, $CaH_4(PO_4)_2.H_2O$, and gypsum, $CaSO_4.2H_2O$. A part of the superphosphate is treated with ammonia salts, and a part with potash salts, or with both, but by far the larger amount is sold as superphosphate.

POTASSIUM AND POTASSIUM MINERALS

USES: The metal potassium has very few direct commercial uses, but the salts of potassium are among the most important in commerce and industries. Only a few of the manifold uses can be enumerated.

Potassium chloride is the most important natural salt of potassium, and it is from it chiefly that the other potassium salts are derived. Its chief use, however, is in the manufacture of artificial land-fertilizers.

The chlorate is used extensively in the textile industry, especially in calico-printing. It is used in the manufacture of oxygen, matches, fireworks, etc., and as an oxidizing agent.

The nitrate is extensively used in meat-pickling and preserving, in the manufacture of gunpowder, fireworks, glass, and artificial fertilizers. In metallurgical processes it is used as an oxidizer and as a flux.

The chromate is used in the manufacture of chrome pigments and in dyeing.

The sulphate is used in the manufacture of fertilizers, alum, potassium carbonate, etc.

The hydroxide is used in the soap, paper and textile industries.

The carbonate is used in the soft-soap industry, and in the manufacture of potassium chromate and potassium ferrocyanide.

The cyanide is used extensively in the extraction of gold and silver by the cyanide process, and as a reducing agent.

Many potassium salts are used in medicine, photography and chemical processes.

POTASSIUM-BEARING MINERALS

SYLVITE: Potassium chloride, KCl; potassium 52.4 per cent

Color: colorless, white, bluish or yellowish-red from impurities.

Luster: vitreous.

Diaphaneity: transparent when pure.

Crystallization: isometric; cubes combined with octahedrons. Crystalline, granular massive and compact forms are most common.

Cleavage: cubic, perfect.

Fracture: uneven. Brittle.

Solubility: very readily soluble, and therefore of rather rare occurrence.

Hardness: 2.

Taste: similar to that of common salt, but more biting.

Specific gravity: 1.97—1.99.

Occurrence: The only commercial occurrence known is at Stassfurt, where it occurs with the carnallite.

Use: important source of potash.

CARNALLITE: Hydrous potassium-magnesium chloride, $KCl.MgCl+6H_2O$; chlorine 38.3, potassium 14.1, magnesium 8.7, water 39.0 per cent.

Color: milk-white, often reddish.

Luster: shining, greasy.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; but crystals are rare.

Cleavage: no distinct cleavage.

Fracture: conchoidal.

Tenacity: brittle.

***Hardness*: 1.**

Streak: white.

Specific gravity: 1.6.

Occurrence and associations: at Stassfurt, Germany, in beds associated with rock salt, kieserite and kainite. The so-called "carnallite region" of the deposit is overlain by salt clay and underlain by kieserite.

Tests: B.B. gives the characteristic violet flame color of potassium, and fuses to a brittle glass. Has a bitter taste, and melts down by absorption of water from the atmosphere.

Uses: Important source of potassium salts of commerce.

Note: The mineral is strongly phosphorescent.

KAINITE: Hydrous chloride of potassium and sulphate of magnesium, $KCl.MgSO_4+3H_2O$.

Color: colorless, white, reddish-white and flesh-red.

Luster: vitreous.

Diaphaneity: transparent to translucent.

Crystallization: monoclinic; tabular and prismatic crystals.

Tenacity: brittle.

Hardness: 2.5—3.

Streak: colorless.

Specific gravity: 2.05—2.2.

Occurrence and associations: in beds of considerable extent and thickness, with rock salt, anhydrite, carnallite, kieserite, and other saline residues in the great Stassfurt deposits of Germany. A section of the deposits known as the "kainite region" is overlain by salt clay and underlain by carnallite and kieserite.

Tests: B.B. easily fusible, giving the flame the violet color characteristic of potassium salts. The fused mass crushed on bright silver and moistened gives the sulphur stain. Soluble in water. Has salty, astringent taste.

Use: Important source of potassium salts.

NITER, POTASSIUM NITRATE, SALTPETER: Nitrate of potassium, KNO_3; potash 46.5 per cent.

Color: white.

Luster: vitreous.

Diaphaneity: translucent.

Crystallization: orthorhombic, resembling aragonite. Generally in crusts and frost-like coatings of needle-like crystals.

Cleavage: one perfect and one fair.

Fracture: subconchoidal to uneven. Brittle.

Hardness: 2.

Specific gravity: 2.09—2.14.

Occurrence: generally in frost-like crusts on the surface of the earth and within certain soils. Animal refuse of various kinds is used in the nitraries of various European and Asiatic countries.

Tests: Flames up vividly on burning coals; colors flame violet (potassium). Dissolves easily in water.

KALINITE, POTASH ALUM, NATIVE ALUM, is a hydrous sulphate of aluminum and potassium, $K_2SO_4.Al_2(SO_4)_3+24H_2O$; potash 9.9 per cent. It occurs in fibrous or massive forms, or in mealy or solid crusts. It is a transparent to translucent white mineral of vitreous luster, hardness of 2—2.5, specific gravity of 1.75, occurring as a frost-like coating on clayey minerals associated with disintegrated sulphides. The alum slates are clays charged with disintegrating pyrite, which forms sulphuric acid. This reacts upon the clay, forming kalinite.

POLYHALITE is a hydrous sulphate of calcium, magnesium and potassium; potash 15.6 per cent, occurring in the Stassfurt deposits and elsewhere with common salt, gypsum, etc.

ALUNITE, ALUMSTONE: A hydrous sulphate of aluminum and potassium, $K_2O.3Al_2O_3.4SO_3.6H_2O$; aluminum 19.6, potassium 9.4 per cent.

Color: white to grayish and reddish.

Luster: vitreous to pearly.

Diaphaneity: transparent to weakly translucent; massive form is opaque.

Crystallization: hexagonal; rhombohedral forms resembling cubes.

Cleavage: one good, one indistinct.

Fracture: flat, conchoidal, uneven.

Tenacity: brittle.

Hardness: 3.5—4.

Streak: white.

Specific gravity: 2.58—2.75.

Occurs: rhombohedral crystals and grains often in a matrix of siliceous material. As a granular, fibrous or massive secondary mineral filling seams in rock which has been acted upon by sulphur vapors. It also occurs as a compact, fine-granular rock of dull-gray color.

Associations: Diaspore and other secondary aluminous minerals.

Rocks: sometimes rhyolite, but mainly trachyte, where it has resulted from alteration by sulphur vapors.

Tests: Infusible, decrepitates. In closed tube gives water, and sometimes ammonium sulphate, and at high temperature sulphur oxides. With soda is infusible, but forms a hepatic mass which will stain silver. Imperfectly soluble in sulphuric and hydrochloric acids.

Uses: When calcined, it yields hydrous sulphates (alums), from which is produced a dyers' mordant known as Roman alum, which is free from chemically combined iron. The tough rock alunite is used for millstones.

Colorado localities: Rosita Hills, Custer County; National Bell Mine and Red Mountain, Ouray County; Iron mine, Leadville; head of Middle Fork of Piedra River, head of South River, Slumgullion Gulch, and other places in the San Cristobal quadrangle.

JAROSITE is a hydrous sulphate of iron and potassium, of various shades of yellow and brown, occurring on the walls of mines. In Colorado it has been found in the Arrow mine, Chaffee County.

PICROMERITE, SCHOENITE: A hydrous sulphate of magnesium and potassium, occurring in the Stassfurt deposits. Potash 23.4 per cent.

APHTHITALITE: Sulphate of potassium and sodium, $(K,Na)_2SO_4$; potash variable, but analyses show 33.24 to 42.5 per cent. It occurs with blödite, halite, etc., in the Stassfurt deposits.

SILICON AND SILICON-BEARING MINERALS

USES: Ferrosilicon is an alloy of iron and silicon used as a deoxidizing agent in casting steel ingots. Silicon copper is an alloy of copper and silicon used as a deoxidizing agent in casting copper and copper alloys. Silicon is a crystalline body having a dark, silvery luster. It is produced in the electric furnace, and is used for the reduction of refractory ores of such metals as chromium and tungsten in the electric furnace. The silicon greedily takes up the oxygen of the ores, and leaves metallic chromium and tungsten. Silicon is also used in the manufacture of rheostats, electrical heaters, and certain forms of chemical apparatus. It is used as a detector in wireless telegraphy.

Silica, SiO_2, in the form of quartz, quartzite, sandstone, etc., is much used. It also occurs in many forms—such as opal, agate and chalcedony—which are prized as cheaper gems and ornamental stones. These useful materials are described elsewhere.

Silicon-bearing minerals are exceedingly numerous, as must be apparent when it is remembered that silicon forms 28 per cent of the outer crust of the earth.

QUARTZ is by far the most important silicon mineral. It is an important constituent of many igneous rocks, especially the members of the granite family, and it is almost the only constituent of the great volumes of sandstone.

Quartz and many of the important silicates are described in the section on "Rock-Making Minerals." The uses of quartz are discussed in the section on "Economic Uses of the Rock-Making Minerals."

SODIUM AND SODIUM MINERALS

USES: The metal is used in the manufacture of cyanides and sodium peroxide, and for the preparation of silicon, boron and magnesium, and certain organic substances. Sodium and sodium amalgam are used as reducing agents in laboratory practice.

Sodium Chloride, Common Salt. The salt of commerce is obtained from three principal sources: (1) deposits of rock salt; (2) the waters of salt lakes and the sea; (3) deposits in the dry basins of ancient salt lakes. Deposits of rock salt may be quarried or mined, and the product dissolved and refined by selective precipitation, in which impurities are precipitated out before the salt is brought down, or are left behind after the salt is precipitated. Another method much used is to bore holes down to the deposit, force water down, and allow it to become partially saturated with salt, and then pump it up and separate the salt, and refine it in the manner described. The waters of salt lakes and the sea are evaporated in open salterns by the heat of the sun. The refining is done in the manner already described. Many dry lake basins contain considerable deposits of impure salt. It is scraped together, hauled to refineries, and treated in much the same way as rock salt.

The commoner uses of common salt are too well known to need enumeration. Large quantities are consumed in the manufacture of various sodium salts, such as the carbonate, the hydroxide, etc. It is used as a preservative of meats, and for domestic purposes; as a source of chlorine in the chlorination process, and in the metallurgy of silver and other metals by other processes. It is also used as a pottery glaze, and in the manufacture of chlorine, hydrochloric acid, and practically all other chlorine compounds.

The hydroxide finds its chief uses in the manufacture of soap, paper pulp, coal-tar dyes, sodium silicate (soluble glass), and in the refining of petroleum after the acid wash.

The dioxide is extensively used with hydrochloric acid to produce hydrogen dioxide for bleaching straw.

The hypochlorite is used for bleaching.

The sulphide is used extensively in the manufacture of soluble soda-glass. The sulphite and the hyposulphite are used in dyeing and calico-printing.

The sulphate is prepared in very large quantities for the manufacture of sodium carbonate. It is also used in glass-making, dyeing and coloring.

The nitrite is used in the preparation of coal-tar colors.

The nitrate is very extensively used as a fertilizer, and to some extent in the manufacturing of nitric and sulphuric acids, and in the making of potassium nitrate ("converted saltpeter"). It is also used in making chlorine in the manufacture of bleaching powder; in glass-making; meat-curing; red-lead making.

Borax, hydrous sodium borate, is used: in metallurgy as a flux and cleanser; for glasses, glazes and enamels in glass, pottery and enameled-ware manufacture; in sanitary and toilet preparations; as a mordant and a base for certain colors in the textile industry; in tanning; in certain paints, driers, and varnishes; in meat-curing, etc. It has many uses in medicine.

The carbonate has an almost unlimited number of uses. Some of them are: glass-making; soap-making; scouring, dyeing, etc., in cloth manufacture; preparation of borax and other sodium salts; the preparation of starch and fatty acids; purification of petroleum, the manufacture of glucose.

The bicarbonate, baking soda, is used in every household, and extensively in making baking-powders.

Sodium cyanide is used in the metallurgy of gold and silver.

MINERALS IMPORTANT AS SOURCES OF SODIUM AND SODIUM SALTS

HALITE, COMMON SALT: Sodium chloride, NaCl.

Color: colorless, white, yellowish, reddish, etc.

Luster: vitreous.

Diaphaneity: transparent to translucent.

Crystallization: isometric; cubes, sometimes with depressed faces.

Cleavage: three, perfect, forming rectangular blocks and plates. Cubical.

Fracture: conchoidal. Brittle.

Hardness: 2.5.

Streak: uncolored.

Specific gravity: 2.1—2.6.

Occurs: mainly in strata with other sedimentary rocks, but also as crusts and granular deposits in desert basins, from the evaporation of saline waters.

Association: gypsum, and other chemical precipitates, such as sodium and potassium sulphates and carbonates.

Alteration: only by solution.

Tests: the saline taste and easy solubility. Before flame it decrepitates and gives intense yellow color.

SODA NITER, CHILI NITER, CHILI SALTPETER: Sodium nitrate, $NaNO_3$; soda 36.5 per cent.

Color: white, reddish and yellowish-brown, gray and lemon-yellow.

Luster: vitreous.

Diaphaneity: transparent to translucent.

Crystallization: rhombohedral; usually granular, massive, in crusts or bedded.

Cleavage: one perfect.

Tenacity: rather sectile; cuts without completely crumbling.

Hardness: 1.5—2.

Specific gravity: 2.24—2.29.

Occurrence: in desert regions, especially about saline lakes.

Tests: Flames up on hot charcoal, giving a yellow light. Colors flame intensely yellow. Dissolves in 3 parts of water at 60° F. Has cooling taste.

MIRABILITE, GLAUBER SALT: Hydrous sulphate of sodium, $Na_2SO_4.10H_2O$; sodium oxide, Na_2O, 19.3 per cent.

Color and streak: white.

Luster: vitreous to subvitreous; loses water and becomes dull.

Diaphaneity: transparent to opaque.

Crystallization: monoclinic; in prismatic forms resembling those of pyroxene.

Cleavage: one perfect, two poor.

Fracture: uneven.

Tenacity: brittle.

Hardness: 1.5—2.

Specific gravity: 1.48.

Occurs: as crusts, layers and granular masses precipitated from alkaline waters in marshes and salt lakes. It is one of the most abundant salts of the "alkali" which covers the soil in many parts of the semi-arid West. In cold weather large quantities separate from the waters of Great Salt Lake and are washed ashore in masses resembling wet, slushy snow. It is collected in heaps above the reach of the waves and saved. It occurs in very large deposits in dry lake basins, notably the Union Pacific lakes southwest of Laramie, Wyoming.

Associations: various other sodium salts, and salts of magnesium, calcium and potassium.

Tests: It is very readily soluble in water. Yields much water in the closed tube. Colors flame intense yellow. Loses water and crumbles when exposed to dry air. Fused mass gives sulphur reaction with bright silver. Tastes cool, then saline and bitter.

Uses: important source of the various commercial salts of sodium.

GLAUBERITE: Sulphate of sodium and calcium, $Na_2SO_4.CaSO_4$; sodium sulphate, Na_2SO_4, 51.1 per cent.

Color: white, gray, yellow, pale green and red.

Luster: vitreous when fresh, dull after exposure to moist air.

Diaphaneity: translucent.

Crystallization: monoclinic; tabular crystals, and less commonly prismatic.

Cleavage: one perfect—parallel to the tabular faces.

Fracture: conchoidal.

Tenacity: brittle.

Hardness: 2.5—3.

Streak: white.

Specific gravity: 2.7—2.85.

Occurrence and association: crystalline, platy masses and crystals with rock salt, thenardite, mirabilite, and other salts characteristic of alkali lakes and marshes.

Tests: B.B. on charcoal breaks up, turns white, colors the flame yellow, and fuses at 1 to a bead which gives the sulphur stain on silver, when crushed and moistened. Partially dissolved in water with separation of calcium sulphate. Soluble in hydrochloric acid. Tastes bitter and weakly saline.

Uses: a source of sodium salts.

NATRON, SODIUM CARBONATE, a hydrous sodium carbonate, $Na_2CO_3+10H_2O$, occurring in soda lakes (alkali) with other carbonates of sodium.

CEOLLPA is a natural sodium carbonate found in La Plata, South America.

TRONA, URAO (Natural Soda): A mixture of sodium carbonate and sodium bicarbonate, $Na_2CO_3.HNaCO_3+2H_2O$; soda 41.2 per cent.

Color: gray to yellowish-white.

Luster: vitreous, glistening.

Diaphaneity: translucent.

Crystallization: monoclinic; flattened and apparently prismatic (domes); forms crusts and bunches of fibrous and columnar structure and granular masses.

Cleavage: one perfect.

Fracture: uneven.

Taste: alkaline.

Hardness: 2.5—3.

Specific gravity: 2.11—2.14.

Occurrence: dissolved in the waters of alkaline lakes, and forming crusts and granular masses along the borders and in marshy areas about the lakes. Often associated with sodium sulphate, common salt, hanksite, glauberite, thenardite, etc.

Tests: In closed tube yields water and carbon dioxide. B.B. colors flame intensely yellow. Soluble in water. Effervesces in acids. Alkaline reaction with test paper.

Colorado localities: A considerable deposit occurs in the alkali lakes of the San Luis valley. It is found sparingly in other alkali lakes and alkali areas.

SODIUM MINERALS OF LESS IMPORTANCE

THENARDITE: Sodium sulphate, Na_2SO_4.

Color: white to yellowish and brownish.

Luster: vitreous to dull.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; pyramidal, short prismatic and tabular. Twins in the form of the letter X are common.

Fracture: rather uneven.

Tenacity: brittle.

Hardness: 2—3.

Streak: white.

Specific gravity: 2.68.

Occurs: frequently in crusts and frost-like surfaces on alkali marshes and alkali lake borders, with various sodium and boron minerals.

Tests: B.B. on charcoal fuses to a mass which gives the sulphur reaction when moistened on bright silver. Soluble in water. Colors blowpipe flame yellow.

Uses: rarely found in commercial quantities.

HANKSITE: An anhydrous sulphatocarbonate of sodium, $4Na_2SO_4.Na_2CO_3$; soda 46 per cent.

Color: white to pale yellow.

Luster: dull vitreous.

Diaphaneity: transparent to translucent.

Crystallization: hexagonal in tabular, prismatic and pyramidal forms.

Cleavage: one distinct.

Fracture: uneven to subconchoidal, brittle.

Hardness: 3—3.5.

Streak: white.

Specific gravity: 2.56.

Occurrence: mainly in association with borax (which frequently incloses it), rock salt, thenardite, glauberite, trona, etc.

THERMONATRITE is a hydrous sodium carbonate, $Na_2CO_3+H_2O$, soda 50 per cent; occurring generally as an efflorescence over the soil in alkali areas in dry regions, and in the waters of alkali lakes. It is a white to grayish and yellowish salt of alkaline taste. It is somewhat sectile—can be cut without complete crumbling.

GAY-LUSSITE, GAYLUSSITE, a hydrous carbonate of calcium and sodium, $CaCO_3.Na_2CO_3+5H_2O$; sodium carbonate 35.8 per cent.

It is a white to yellowish-white, vitreous, translucent mineral, occurring in monoclinic crystals of elongated and flattened wedge shape, as a result of the evaporation of the waters of soda lakes. It has a perfect cleavage, a conchoidal fracture, a hardness of 2—3, a specific gravity of 1.93—1.95. *Tests*: In closed tube flies to pieces and becomes opaque. B.B. fuses readily to white enamel, coloring flame intense yellow. Effervesces in acids.

SODIUM-RICH MINERALS DESCRIBED ELSEWHERE

Cryolite, Borax, Ulexite; Albite and other Plagioclases, Aegirite, Jadeite, Pectolite, Nephelite, Cancrinite, Sodalite, Hauynite, Noselite, Lazurite, Wernerite (Scapolite), Natrolite.

ALKALI: The name "alkali" is given to the crusts and powdery masses of soluble salts formed on and in the soils in many parts of the semi-arid West. The salts are not *alkalies* in the chemical sense although they are largely salts of the basic elements. The "alkali" is usually a mixture of several salts, and its composition varies widely from place to place. The commonest "alkali" salts are:

Sodium sulphate. See Mirabilite, Glauber Salt, Thenardite.
Sodium chloride. See Halite, Common salt.
Magnesium sulphate. See Epsom Salt, Epsomite.
Magsenium chloride. See Carnallite. (The form in which the magnesium chloride occurs is doubtful.)
Calcium sulphate. See Gypsum.
Sodium carbonate. See Trona and Natron.
Sodium bicarbonate. See Trona, Urao.
Potassium sulphate. See Kalinite and Polyhalite.
Potassium chloride. See Sylvite, Kainite, Carnallite.

Origin: In the ordinary processes of soil formation from rock disintegration and decay these salts are formed. If the rainfall is sufficient they are dissolved and carried away in solution, and the soil is left free from them. On the other hand, in the arid and semi-arid regions quantities of the salts remain and are taken into solution by the rain. On evaporation of the water on and in the soil the salts are deposited as alkali.

STRONTIUM AND STRONTIUM MINERALS

STRONTIUM is one of the alkali earth metals, and is very widely, but sparingly, distributed in various rocks and soils, and in certain mineral waters.

USES: The metal strontium is not used, but the hydroxide is extensively used in beet-sugar refining in Europe. The nitrate is used in fireworks to produce a strong crimson color. Certain strontium salts are used in medicine. Strontianite finds a limited use in the manufacture of refractory basic bricks. Clay or clay ironstone and the powdered mineral are mixed with asphalt or other heavy hydrocarbon, molded, sprinkled with a glazing material, and burned.

STRONTIANITE: Strontium carbonate, $SrCO_3$, with occasionally a little calcium and barium.

Color: white, to pale green, to yellowish and brownish.

Luster: vitreous on crystal faces and cleavage surfaces; fractured surfaces subvitreous.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; often acicular and acute pear-shaped; twinning sometimes gives hexagonal appearance.

Cleavage: one (prismatic) nearly perfect, another poor.

Fracture: uneven.

Tenacity: brittle.

Hardness: 3.5—4.

Streak: white.

Specific gravity: 3.68—3.71.

Occurs: as fibrous and radiating, needle-like masses of crystals; also in granular masses, and in distinct crystals, frequently pear-formed.

Associations: other carbonates, such as calcite, magnesite, etc.

Tests: B.B. swells, sprouts and fuses on thin edges, giving flame strontia-red color; fused mass gives alkaline reaction when crushed and moistened on test papers; crushed and moistened with hydrochloric acid, it gives intense red color to flame; soluble with effervescence in cold dilute acids. Calcite and aragonite are infusible, and give paler, yellowish-red flame.

Uses: source of strontium salts, used in fireworks; changed to hydroxide and used in sugar-refining; refractory bricks are made from strontianite and clayey ironstone. The demand is very limited.

CELESTITE, CELESTINE: Strontium sulphate, $SrSO_4$. Calcium and barium sometimes replace part of the strontium.

Color: white, to gray, to bluish; sometimes yellowish and reddish.

Luster: vitreous to pearly.

Diaphaneity: transparent, to translucent, to opaque.

Crystallization: orthorhombic; tabular forms similar to those of barite, bounded by pyramidal and vertical faces.

Cleavage: two perfect at right angles to the tabular faces; a third less perfect.

Fracture: uneven.

Tenacity: brittle.

Hardness: 3—3.5.

Streak: white.

Specific gravity: 3.95—3.97.

Occurs: in crystals, fibrous and radiating bunches, and occasionally in cleavable and granular masses; cavities in sandstones, limestones, clays, gypsum and rock salt.

Associations: gypsum, sulphur, rock salt, (limestone), calcite, lead and zinc sulphides, dolomite, and other minerals of sedimentary rocks.

Tests: B.B. fuses to white pearl or enamel-like glass, coloring flame strontia-red, or crimson; fused mass crushed and moistened gives alkaline reaction on test paper; on coal fuses to mass which, treated with hydrochloric acid and alcohol, gives deep-red flame; with soda on charcoal gives sulphur reaction on silver.

Uses: preparation of nitrate of strontium for fire-works; in sugar-refining; medicinal preparations.

BARYTOCELESTITE contains much barium.

CALCIOCELESTITE contains much calcium.

SULPHUR AND SULPHUR-BEARING MINERALS

USES: The most important use of sulphur is in the manufacture of sulphuric acid. But a very large amount is used in making paper pulp. Less important uses are: the manufacture of gunpowder, fireworks, disinfectants, germicides, insecticides, matches; and in vulcanizing rubber. It is used in many medicinal preparations, and is burned as a bleaching agent.

Sulphuric acid: The refining of petroleum and the manufacture of superphosphate fertilizer from phosphate rock consume by far the larger part of the sulphuric acid manufactured. In the former it is said that the production of a gallon of kerosene requires a pound of sulphuric acid. In the making of superphosphates the consumption of acid is approximately equal to that of phosphate rock. A ton of rock requires from 1,700 pounds to one ton of acid. Much sulphuric acid is used in the manufacture of the mixed acids used in the manufacture of explosives. The manufacture of sulphite paper pulp takes a considerable tonnage of acid. It is used in the manufacture of hydrochloric, nitric and nitrous acids, and for carbonating many bottled waters. The minor uses are too numerous to mention.

Sulphuretted hydrogen has many uses in chemical processes.

Sulphur dioxide and sulphurous acid are used as bleaching agents.

Sulphur trioxide represents a stage in the manufacture of sulphuric acid.

The raw materials of sulphuric acid manufacture are mainly: (a) sulphur; (b) metallic sulphides, chiefly pyrite; (c) sulphur gases produced in the smelting of sulphide ores; (d) sulphur and sulphur compounds recovered as by-products in manufacturing alkalies and ammonium sulphate, and from the spent oxides from gas manufacture. The total production of sulphuric acid in the United States exceeds 3,000,000 tons annually.

We import large quantities of pyrite for the manufacture of sulphuric acid, and at the same time our lead, zinc, copper and other smelters are pouring into the atmosphere sulphur gases enough to make more sulphuric acid than we now produce from all sources. At the present time about one-third of the sulphuric acid used is made from smelter gases and other by-products.

SOURCES OF SULPHUR

Native sulphur deposits are by far the most important sources of the sulphur of commerce. It is also derived from the metallic sulphides, especially pyrite and marcasite. Many processes have been patented for the separation of sulphur from the sulphur gases formed in the smelting of sulphide ores, but at present comparatively little is produced in this way.

NATIVE SULPHUR

The principal deposits of native sulphur belong to one of the three types:

1. Those derived from gypsum, and consequently associated with sedimentary rocks.

2. Those formed by the precipitation of sulphur about the vents of active and dormant volcanoes.

3. Deposits about hot springs, or in areas where hot springs have existed.

The deposits of the first type are the most important. The sulphur is probably derived from the gypsum through the reducing (oxygen-removing) agency of carbonaceous materials, such as bitumen, in the associated rocks.

The sulphur of volcanic areas may be the result of the oxidation of hydrogen sulphide in the presence of water ($H_2S+H_2O+O=2H_2O+S$).

The sulphur of hot spring areas may result from similar processes, since hydrogen sulphide is a common gas in such areas.

Other deposits are formed by the disintegration of metallic sulphides, such as pyrite, marcasite, etc.

Colorado: The most promising deposits of sulphur in Colorado appear to be those of Vulcan, Gunnison County, and Trout Creek, Mineral County. A number of other deposits are reported.

SULPHUR: As found native, it varies from pure sulphur to an admixture of sulphur, clay, disintegrated rock, bitumen and other impurities.

Color: chiefly sulphur-yellow and other shades of yellow, but sometimes gray, brownish, greenish and reddish.
Luster: resinous.
Diaphaneity: transparent to translucent.
Crystallization: orthorhombic; pyramids, and tabular forms; more commonly in masses, crusts and coatings.
Cleavage: poor.
Fracture: conchoidal to uneven.
Tenacity: brittle to weakly sectile.
Hardness: 1.5—2.5.
Streak: white.
Specific gravity: 2.05—2.09.

Tests: Melts at 108° C., and burns at 270°, with a bluish flame, yielding the pungent fumes of sulphur dioxide. Insoluble in water and the acids, but soluble in carbon bisulphide.

SULPHUR-BEARING MINERALS ARE DESCRIBED UNDER IRON, COPPER, LEAD, ZINC, ETC. A few of the more important are: Pyrite, Marcasite, Pyrrhotite; Chalcopyrite, Chalcocite, Bornite; Galena; Sphalerite.

SELENIUM AND THE SOURCES OF SELENIUM

USES: The greatest demand for selenium is for the manufacture of red glass used in railway signals, red enamel ware, and in the enameling of steel.

Selenium is a fairly good conductor of electricity in the light, but a very poor conductor in the dark. This peculiar behavior is at the basis of many of its uses in electrical science. It is used in apparatus for: automatically lighting and extinguishing the flame on gas buoys; controlling street lights, electric signs, and moving pictures; exploding torpedoes by a ray of light; controlling torpedo boats; burglar alarms; measuring the intensity and variation in light, and measuring the Roentgen rays; transmitting sounds and photographs by telegraph.

SOURCES: Minerals containing selenium as an essential element are fairly numerous, but they occur in very small quantities, and are not commercial sources of the metal. The chief and practically only source of the selenium of commerce is the residual anode muds formed in the electrolytic refining of blister copper, where it is associated with gold, silver, and other impurities. The quantity of selenium varies with the source of the ore from which the blister copper is made. But as selenium and its compounds are very volatile, it is probable that only a small part of the selenium content of the ores gets into the copper. The amount of selenium in the blister copper treated at a certain refinery ran from 13 to 170 pounds to 100 tons of copper.

Nearly all the uranium and vanadium ores of western Colorado and eastern Utah contain selenium in amounts easily detected in the laboratory, but probably not exceeding a pound of selenium to the ton of rock.

Many gold and silver ores contain selenium, as for example those of Tonopah, Nevada; parts of the San Juan, Hauraki, New Zealand.

It is common in pyrite, and finds its way into the residues formed in the manufacture of sulphuric acid from pyrite, and occasionally into the acid itself.

The following are some of the minerals in which selenium is an essential element:

AGUILARITE, $Ag_2S.Ag_2Se$ (selenium 14.6 per cent.) occurs sparingly at Guanajuato, Mexico. It is an iron-black, opaque mineral of brilliant metallic luster, a hardness of 2.5, a specific gravity of 7.6. It has a hackly fracture but no cleavage, and is sectile.

It occurs in crystals of the isometric system.

BERZELIANITE: Cu_2Se (selenium 38.4 per cent.) occurs in thin crusts and scattered grains. It is a soft silver-white mineral of metallic luster and shining streak and a specific gravity of 6.7. In the open tube it gives a red deposit of selenium and white crystals of selenium dioxide. B.B. on charcoal fumes of selenium on metallic copper.

CLAUSTHALITE, PbSe (selenium 27.7 per cent.) is described under Lead and Lead Minerals.

CROOKESITE (Cu,Tl,Ag)Se, is described under Thallium.

EUCAIRITE, $Cu_2Se.AgSe$ (selenium 31.6 per cent.) is a massive, granular, silver-white to lead-gray mineral having a specific gravity of 7.5, a hardness of 2.5. Easily fusible.

GUANAJUATITE, Bi_2Se_3 (selenium 36.3 per cent.) occurs in needle-like crystals, and fibrous or foliated and massive, granular. It is a bluish-gray mineral of metallic luster, a hardness of 2.5–3.5, a specific gravity of 6.25–6.62, a metallic luster and a distinct cleavage.

LEHRBACHITE, PbSe with HgSe (selenium 24.4–25 per cent.). Massive, granular. *Specific Gravity* 7.8. Lead-gray to iron-black.

NAUMANITE (Ag_2,Pb)Se (selenium about 26.8 per cent), an iron-black mineral occurring in cubes, massive, granular and in plates. Cubical cleavage. Specific gravity, 8.0.

ONOFRITE, Hg (S,Se), (selenium 4.7—6.6 per cent.), occurred in considerable quantity at Marysvale, Utah.

SELEN-TELLURIUM, selenium 3, tellurium 2.

TIEMANNITE, HgSe, (selenium 28.3 per cent.), a steel-gray to blackish lead-gray, mineral of metallic luster, black streak, a specific gravity of 8.2—8.47, occurring in massive and compact form at Marysvale, Utah, where it was mined for mercury.

TILKERODITE is a cobalt-bearing variety of Clausthalite.

GEM MINERALS AND SEMI-PRECIOUS STONES

The qualities which give a mineral value as a gem are color, luster, hardness and transparency. Comparatively few gems excel in all four of these qualities, and a number possess only two in a high degree. The diamond, as a rule, excels only in luster, hardness and transparency. The addition of fine color, such as red or blue, makes it the most valuable of gems. The choicest rubies have all four qualities in a high degree. Hardness does not in itself add to the beauty of the gem, but it protects the luster, form and transparency of the gem. A high degree of hardness is more important in transparent gems than in the translucent and opaque. A scratched or marred surface is fatal to a transparent gem, whereas pearl, turquoise and amber retain their particular beauty even though their surfaces may be roughened by wear.

Apart from a comparatively few of the rarer and costlier gems, fashion has much to do with the demand for, and price of, precious stones.

AMAZONSTONE, a variety of feldspar, when of uniform color and free from flaws is prized as a cheaper gem. It is found in the Pikes' Peak region. The best now comes from Florissant.

AQUAMARINE is a bluish-green beryl. Found at Mt. Antero, Buffalo Mountain, near Creswell.

BERYL: A silicate of beryllium (glucinum) and aluminum, $3BeO.Al_2O_3.6SiO_2$; aluminum 19 per cent, glucina 14 per cent.

Color: emerald-green, pale green, light blue, yellow, white, and pale rose-red.

Luster: vitreous to resinous.

Diaphaneity: transparent to translucent.

Crystallization: hexagonal; long prismatic crystals; also in coarse columnar and granular masses.

Cleavage: poor.

Fracture: conchoidal to uneven.

Tenacity: brittle.

Hardness: 7.5—8.

Streak: white.

Specific gravity: 2.63—2.8.

Occurrence: most commonly in pegmatite veins, but also in metamorphic rocks, such as slates, schists and gneisses.

Associations: phenacite, chrysoberyl, apatite, tourmaline, rutile, quartz, feldspar, pollucite.

Tests: B.B. alone, unchanged, except to become cloudy. At very high temperature forms a slag at 5.5. With borax it forms a colorless glass. Emerald forms a green glass. Not affected by acids.

Colorado localities: various places in Boulder County, especially near Glendale; Mount Antero in Chaffee County; and many other localities.

CALIFORNITE is a translucent, massive, compact vesuvianite, of gray to green color, mottled with brighter green of various shades. It resembles jade in color, hardness, toughness and texture. The choicest specimens are nearly grass-green and beautifully translucent.

CHRYSOBERYL, CYMOPHANE: A beryllium aluminate, $BeO.Al_2O_3$; aluminum 42.4 per cent.

Color: various shades of green.

Luster: vitreous.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; pseudohexagonal, tabular crystals.

Cleavage: fair.

Fracture: uneven to conchoidal.

Tenacity: brittle.

Hardness: 8.5.

Streak: uncolored.

Specific gravity: 3.5—3.8.

Occurs: frequently in crystal form, but also granular, and in rolled pebbles.

Tests: B.B. alone, unaltered, but very difficultly fusible with borax. Not attacked by acids. With cobalt nitrate gives fine blue.

Remarks: Valuable only as a gem.

Alexandrite is emerald-green, but columbine-red by transmitted light.

Cat's Eye is greenish, chatoyant.

DIAMOND: Pure crystalline carbon.

Color: white or colorless; also shades of yellow, red, brown, green, blue and black.

Luster: adamantine to greasy and dull.

Diaphaneity: transparent to translucent and opaque in bort and carbonado.

Crystallization: isometric; in modified cubes, octahedrons, tetrahedrons, etc.; often distorted and irregular.

Cleavage: octahedral, perfect.

Fracture: conchoidal. Brittle.

Hardness: 10 and over.

Specific gravity: 3.516—3.525 for crystals; 3.15—3.5 for carbonado and bort.

Occurrence: in alluvium associated with quartz, gold, platinum, zircon, octahedrite, brookite, rutile, topaz, corundum, tourmaline, etc. The South African diamonds occur in volcanic necks filled with peridotite. The Arkansas diamond area is in peridotite.

Tests: At very high temperature, in an atmosphere of oxygen, it burns to carbon dioxide. Heated intensely out of contact with air, it forms a kind of coke. It is not acted upon by acids or alkalies. Positively electrified by friction.

EMERALD is a bright, emerald-green beryl, highly prized as a gem.

EPIDOTE, in perfectly transparent, dark-green crystals, is sometimes cut as a gem stone.

HIDDENITE, an emerald-green spodumene. When clear and flawless, brings a high price as a gem. Found at Hiddenite, North Carolina.

HYACINTH is a transparent, brownish to red-orange zircon, used as a gem.

IOLITE is occasionally cut as a gem.

KUNZITE is a beautiful pink or lilac variety of spodumene much prized as a gem.

MOONSTONE is a feldspar having a changing luster and a play of colors, which make it highly prized as a gem stone. Oligoclase, labradorite, albite and orthoclase sometimes possess these properties.

OPAL: Silica, SiO_2, with a varying amount of water.

Color: white, yellow, wine-red, green, gray, bluish-green, often showing a beautiful play of colors.

Luster: vitreous, to subvitreous, to resinous and pearly.

Diaphaneity: transparent in hyalite to nearly opaque in the darker-colored varieties.

Crystallization: amorphous; in seams, crusts, globular masses, and in earthy forms.

Cleavage: none.

Fracture: conchoidal.

Hardness: 5.5—6.5.

Streak: white.

Specific gravity: 1.9—2.3.

Occurrence: It is found in fissures and cavities in igneous rocks, particularly lavas; also in limestone in masses and nodules similar to the flint concretions. See also the varieties.

Fire Opal is distinguished by fire-like reflections, which vary in color on turning the stone.

Precious Opal shows a play of delicate colors.

Wood Opal is wood replaced by opal.

Hyalite is a glass-clear, colorless opal, occurring in globular and botryoidal crusts. Sometimes only translucent.

ORIENTAL TOPAZ is a clear yellow corundum.

ORIENTAL EMERALD is a fine green corundum.

ORIENTAL AMETHYST is purple or amethystine corundum.

PERIDOT, Jewel Olivine, Precious Olivine, are names applied to a pale yellowish-green, transparent olivine brought from the east end of the Mediterranean and extensively used for jewelry. It is not found in America.

PHENACITE: Orthosilicate of beryllium, $2BeO.SiO_2$.

Color: colorless to bright wine-yellow, pale rose-red and brown.

Luster: vitreous.

Diaphaneity: transparent to translucent.

Crystallization: rhombohedral; lenticular and prismatic forms.

Cleavage: one distinct.

Fracture: conchoidal. Brittle.

Hardness: 7.5—8.

Specific gravity: 2.97—3.

Occurrence: It is generally found in metamorphic rocks or regions of metamorphic rocks.

Associations: topaz, amazonstone, quartz and beryl, adularia and apatite.

Tests: B.B. alone unaltered; with borax fuses very slowly to a transparent glass. With soda yields a white enamel; with more soda swells and becomes infusible. With cobalt nitrate solution becomes dull-blue.

Colorado localities: Topaz Butte, near Florissant, and at Mount Antero and Devils Head.

QUARTZ: Many varieties of quartz and related silica minerals are used as cheaper gems and ornamental stones.

Agate is a variegated chalcedony, either banded or clouded. The banding is generally concentric and is due to impurities in the solution from which the mineral was deposited. The occurrence is the same as that of chalcedony.

Agatized Wood is formed by the replacement of the vegetable matter (and structure) by chalcedonic silica having the agate banding or clouding.

Amethyst, Amethystine: Clear purple or violet-blue quartz. The color is probably due to manganese.

Aventurine quartz is spangled with mica or hematite, or other mineral.

Bloodstone: see *Heliotrope.*

Carnelian, Sard, is a clear chalcedony, varying in color from red to brown.

Cat's Eye, an opalescent quartz resembling true Cat's Eye, which is a variety of chrysoberyl.

Chalcedony is a cryptocrystalline quartz having a waxy luster, and varying in color from white to pale blue, to brown, etc. It occurs in thin seams and bands, and as botryoidal crusts and fillings in cavities.

Chrysoprase is chalcedony colored apple-green by nickel oxide.

Citrine, False Topaz, has a dull, opaline luster, a yellow color, and is transparent to subtransparent. It resembles yellow topaz, and is used in cheap jewelry.

Heliotrope, Plasma, Bloodstone, is a translucent to weakly transparent chalcedony, varying in color from bright to deep green and emerald. When dotted with red jasper it is called heliotrope or bloodstone. Plasma may have white dots.

Jasper is impure, opaque quartz, commonly red or yellow or brown from the presence of iron. Black and deep-brown jaspers are somewhat common.

Moss Agate is similar to agate, but the coloring is in arborescent or moss-like forms.

Onyx is similar to agate, but the bands are straight.

Plasma: see *Heliotrope.*

Prase is dull leek-green, translucent quartz.

Rock Crystal, Bristol Diamonds, Herkimer Diamonds, Lake George Diamonds, Brazilian Pebbles, are names for more or less perfectly transparent crystals of quartz, which are used to a limited extent in the manufacture of optical goods, and more extensively in the manufacture of novelties and low-priced jewelry.

Rose Quartz is pale-pink to rather deep rose color. The color is probably due to titanium or manganese, and is rarely or never permanent, but fades on exposure to the sun.

Rutilated Quartz, Sagenite, contains needle-like crystals of rutile, sometimes forming a network.

Sardonyx is like onyx, but contains layers of carnelian (sard).

Sapphire Quartz has an indigo or Berlin-blue color.

Smoky Topaz, Smoky Quartz, Cairngorm Stone, Morion, varies in color from yellowish to smoky-brown, in transparency from transparent to nearly opaque. Good specimens of smoky quartz (smoky topaz) are found in the Pikes Peak region.

Star Quartz, Asteriated Quartz, contains whitish or colored radiating lines along the diametral planes.

Topaz: Quartz crystals are often called topaz. See Smoky Topaz.

RUBELLITE is a red to pinkish tourmaline, occasionally clear and transparent, and of very delicate tints.

RUBY, ORIENTAL RUBY, is red corundum. The stones are selected largely by the particular shade of red they possess. The choicest rubies are more valuable than diamonds.

SAPPHIRE is transparent blue corundum of fine, velvety sheen. The corn-flower blue sapphire is most highly prized, but indigo-blue, smalt-blue, Berlin-blue and greenish and grayish-blue sapphires are used as gems.

Star Sapphire is a variety showing a star-shaped opalescence when viewed in the direction of the vertical axis.

STAUROLITE: Symmetrically formed crystals of good color and free from flaws have been polished for gems and ornamental stones.

SPINEL: Magnesium aluminate, $MgO.Al_2O_3$.

Color: various shades of red, passing into blue, green, yellow, brown and black.

Luster: vitreous to splendent to dull.

Diaphaneity: transparent to nearly opaque.

Crystallization: isometric; octahedral habit.

Cleavage: rather poor.

Fracture: conchoidal.

Tenacity: brittle.

Hardness: 8.

Streak: white.

Specific gravity: 3.5—4.1.

Occurrence: in granular limestone and with calcite in serpentine, gneiss, etc.

Associations: chondrodite, ruby, clintonite.

Tests: B.B. alone infusible. Slowly soluble in borax; more rapidly in salt of phosphorus, in which it gives a reddish bead while hot, and faint chrome-green when cold. Decomposed by fusion with potassium bisulphate.

Ruby Spinel is a clear red or reddish, translucent to transparent variety.

Picotite, Chrome Spinel, is a dark yellowish-brown or greenish-brown variety containing chromium.

TOPAZ: A silicate of aluminum and fluorine, usually containing hydroxyl, (OH); $Al_2SiO_4(OH, F)_2$; or, without OH, it may be written $(Al, F)_2SiO_4$.

Color: straw-yellow, to colorless, to wine-purple, to grayish-white, bluish and reddish.

Luster: vitreous.

Diaphaneity: transparent to weakly translucent.

Crystallization: orthorhombic; prismatic, often with faces striated.

Cleavage: basal, perfect.

Fracture: subconchoidal, to uneven. Brittle.

Hardness: 8.

Streak: uncolored.

Specific gravity: 3.4—3.6.

Occurrence: crystals, crystal grains, columnar, granular and rarely massive.

Associations: minerals of granite, rhyolite; also cassiterite, fluorite and tourmaline.

Rocks: granites, rhyolites, and in furmarolic deposits.

Tests: B.B. infusible. Mixed with pulverized, fused salt of phosphorus and fused in a closed tube, it etches the glass, giving it a rough, frosted appearance. The pulverized mineral, moistened with cobalt solution and heated, gives a fine blue color (alumina). Slightly attacked by sulphuric acid.

Colorado localities: Pikes Peak (colorless to pale blue); Nathrop (wine-colored); Chalk Mountain, near Leadville (wine-colored); occasionally in San Juan.

TURQUOIS, TURQUOISE: A hydrous phosphate of aluminum with copper oxide, $CuO.3Al_2O_3.2P_2O_5.9H_2O$.

Color: sky-blue to apple-green.

Luster: feeble, somewhat waxy.

Diaphaneity: opaque or faintly translucent, crystals transparent.

Crystallization: triclinic; (extremely rare), small prismatic with striated faces.

Cleavage: probably two.

Tenacity: brittle.

Hardness: 5—6.

Streak: white or greenish.

Specific gravity: 2.6—2.84.

Occurs: massive, amorphous or cryptocrystalline; reniform, stalactitic and incrusting masses; rolled masses.

Rocks: commonly in trachyte.

Tests: In closed tube decrepitates, yields water, turns brown or black. B.B. turns brown and looks glassy, but does not fuse; colors flame green (copper). Reacts for copper. Soluble in hydrochloric acid.

Remarks: Valuable chiefly as an ornamental stone. Found in New Mexico and Colorado. A crystallized turquoise is found in Campbell County, Virginia.

MINERALS SOMETIMES USED AS GEMS AND SEMI-PRECIOUS STONES, DESCRIBED ELSEWHERE: Andalusite, Axinite, Azurite, Cyanite, Diopside, Epidote, Garnet, Iolite, Jade, Jasper, Malachite, Mexican Onyx, Olivinite, Rhodonite, Serpentine, Sodalite, Spodumene, Staurolite, Tourmaline, Varacite, Vesuvianite, Zircon.

METALLIC MINERALS AND THEIR USES

IRON AND IRON MINERALS

USES: Pure iron is comparatively little used. The product of the blast furnace is known as cast iron. It contains much carbon, but the carbon is not evenly distributed throughout the mass and is only partially alloyed with the iron. Cast iron cannot be drawn or hammered into useful forms, and so finds comparatively little direct use in the industries. Of the 27,300,000 long tons of cast iron produced in this country in 1910, over 26,000,000 long tons was converted into steel before it entered into the general trade of the country.

STEEL is an alloy of iron and carbon, usually with small amounts of silicon and manganese, in which the carbon ranges from a fraction of 1 per cent to 3 per cent. Special forms of steel are made by the addition of manganese, tungsten, molybdenum, uranium, vanadium, nickel, chromium, either separately or two or more together. These special steels are distinguished by the name of the metal added, as manganese steel, tungsten steel, molybdenum steel, chrome-tungsten steel.

Of the steel produced in this country, about one-third is used by the railways for rails, rolling-stock, bridges, and other purposes. The next most important use is as structural material in buildings, bridges, piping, etc. The manufacture of machinery, stoves and furnaces, tools, rods, wire, bolts, nails, sheet iron, tin plate, and other commercial products, accounts for the balance.

Certain iron ores of low grade are used as fluxes in the smelting industry, especially in treating silver ores high in silica.

Mineral paints, such as ochres, umbers, siennas, are made from soft impure iron ores.

Many salts of iron are extensively used in the industries. Copperas, green vitriol, or iron sulphate, $FeSO_4.7H_2O$, is the most important. The largest part of the copperas manufactured is used as a mordant in dyeing, but a considerable amount is consumed in the manufacture of Venetian red, Indian red and Prussian blue, pigments; rouge (a polishing powder); and inks.

The acetates and nitrates are used in the textile industries as mordants, oxidizing and weighting materials, to modify color tones and to increase the stiffness and density of fabrics.

Iron alums are also used in the textile industry, but not so extensively as formerly.

IRON MINERALS IMPORTANT AS ORES OF IRON

HEMATITE: Sesquioxide of iron, Fe_2O_3; metallic iron 70 per cent. It is the favorite ore.

Color: bright steel-gray to iron-black in the hard crystalline forms, to red and reddish-brown in the soft and ochreous forms, and black and blue-black in some soft varieties, especially those carrying manganese.

Luster: from brilliant, metallic in specular hematite, to submetallic in hard granular ores, and dull and earthy in the soft ores.

Diaphaneity: opaque.

Crystallization: rhombohedral; crystals are rarely seen in ores.

Cleavage: not seen in ores.

Fracture: shows fine to coarse granular surface, sometimes fibrous, sometimes subconchoidal. Brittle.

Hardness: 5.5—6.5 for solid crystalline forms, but may range from 1 to 5 for the "soft red," "soft black" and ochreous varieties.

Streak: cherry-red to reddish-brown in the commoner varieties, to steel gray in specular ore, and black in the manganiferous varieties.

Specific gravity: 4.9—5.3 for the solid crystalline varieties, while the soft and powdery ores may fall as low as 3.75 to 4.

Occurs: mainly in bedded deposits associated with sedimentary and metamorphic rocks.

Associations: other ores of iron, especially limonite, turgite, etc. Siderite is sometimes present.

Tests: Soluble in strong hydrochloric acid; on coal R.F. becomes magnetic and with soda forms metallic powder.

Differences: Magnetite has black streak and is attracted by magnet; limonite has brown to yellow streak and is hydrous.

Varieties: (a) Red hematite, varies from compact, crystalline forms, called "hard red," to soft, powdery and ochreous forms, called "soft red." In the harder forms fresh surfaces free from powder are steel-gray to iron-black.

(b) Specular hematite is usually in brilliant crystal grains or flakes (micaceous hematite), but is sometimes almost massive. It is commonly weakly magnetic.

(c) Kidney ore is in rounded, kidney-shaped masses, often concentrically formed of layers of fibers radially arranged.

(d) Clay iron-stone is a clayey (often sandy) hematite of reddish to brownish color, rarely used as ore in America.

(e) "Clinton ore," "fossil ore," "flax-seed ore," "oolitic ore," "pea ore," "dyestone ore" are names applied to a red hematite first discovered in the Clinton formation (Silurian), at Clinton, N. Y., but now mined locally in this formation from New York to Alabama. In some places it is rich in small fossils, in others oolitic grains of various sizes are abundant.

MAGNETITE: Magnetic oxide of iron, Fe_3O_4 or $FeO.Fe_2O_3$; metallic iron 72.4 per cent.

Color: iron-black.

Luster: metallic to submetallic and dull.

Diaphaneity: opaque.

Crystallization: isometric; octahedrons and dodecahedrons. Crystals are rare in magnetite as an ore of iron.

Cleavage: not distinct; parting parallel to the octahedron is often distinct.

Fracture: uneven.

Tenacity: brittle.

Hardness: 5.5—6.5.

Streak: iron-black.

Specific gravity: 5.17—5.18.

Occurs: (a) massive, granular; (b) massive, with laminated structure; (c) as fine, soft, black powder; (d) as black sand on shores, etc.

Associations: the minerals of metamorphic rocks; also titanium minerals, pyrite and apatite.

Rocks: most commonly in metamorphic rocks.

Tests: very hard to fuse, soluble in hydrochloric acid; O. F. is oxidized to hematite which is not attracted by the magnet. Gives regular iron tests.

LODESTONE is a variety of magnetite which acts as a natural magnet.

LIMONITE, BROWN HEMATITE: A hydrous sesquioxide of iron, $2Fe_2O_3.3H_2O$; metallic iron 59.8 per cent, oxygen 25.7 per cent, water 14.5 per cent.

Color: various shades of brown when pure; yellowish-brown to yellow when impure. Nodules often show shiny, black surfaces.

Luster: silky, submetallic, to dull and earthy.

Crystallization: not crystallized.

Fracture: smooth to finely granular and fibrous.

Hardness: 5—5.5, but earthy forms vary from 2 to 5.

Streak: yellowish-brown.

Specific gravity: 3.6—4, but earthy forms run lower.

Occurs: in bedded deposits with sedimentary rocks. It is secondary, resulting from the alteration of other ores and minerals carrying iron.

Associations and impurities: other ores of iron, sand, clay, manganese, phosphates, etc.

Varieties: (a) Compact, massive ore resembling hematite except in color and luster. Often occurs in open pipy masses showing botryoidal forms and lustrous black surfaces.

(b) Ochreous limonite, yellow-ochre is generally impure from the presence of clay, sand, and often organic matter.

(c) Bog ore is generally a loose, open, ochreous ore commonly carrying many impurities.

Tests: Soluble in hydrochloric acid; gives water in the closed tube, and is changed to Fe_2O_3.

Differences: from magnetite and hematite by yellowish streak, yielding water, non-crystalline form, brownish color.

GÖTHITE: A hydrous sesquioxide of iron, $Fe_2O_3.H_2O$. A few deposits are large enough to be mined as an ore. It occurs in fibrous, radiating, concentric and massive forms. It crystallizes in prisms, plates and scales, has an uneven fracture and a good cleavage. It resembles limonite in hardness, specific gravity, streak and color. It contains 62.9 per cent iron.

TURGITE: A hydrous sesquioxide of iron, $2Fe_2O_3.H_2O$; has a red streak, but is otherwise like limonite. It is not known as an ore.

SIDERITE: A carbonate of iron $FeCO_3$; often contains calcium, magnesium, and sometimes manganese; metallic iron 48.3 per cent.

Color: gray to yellowish-gray to brown. Often discolored by oxidation of the iron.

Luster: vitreous to pearly.

Diaphaneity: translucent to opaque.

Crystallization: hexagonal, rhombohedral. Rhombohedral faces are commonly curved.

Cleavage: rhombohedral, perfect.

Fracture: uneven or subconchoidal.

Hardness: 3.5—4.

Streak: white.

Specific gravity: 3.83—3.88.

Occurrence: commonly massive, granular, but frequently in well-defined crystals lining cavities and seams. It is often found in nodules and concretions in shales and in bands associated with coal seams.

Association: other carbonates, such as calcite, dolomite and ankerite.

Rocks: more common in the sedimentary rocks, but frequently in altered igneous rocks.

Alteration: by solution and by oxidation to limonite, hematite, and other iron minerals.

Economic: sometimes occurs in sufficient quantity to be used as an ore of iron. It is mined in Ohio and Pennsylvania.

ILMENITE, MENACCANITE, TITANIC IRON ORE: Oxide of iron and titanium, $FeO.TiO_2$; iron 36.8; titanium 31.6 per cent.

Color: iron-black.

Luster: submetallic.

Diaphaneity: opaque.

Crystallization: hexagonal, trirhombohedral in thick tabular crystals; also acute forms.

Cleavage: none recognized.

Fracture: conchoidal.

Hardness: 5—6.

Streak: submetallic, powder brownish-red to black.

Specific gravity: 4.5—5.

Magnetism: weak, but pronounced.

Occurrence: Titanium in small quantity is found in nearly all igneous rocks, and it is believed to occur mainly in the forms of titanite and ilmenite. The latter is less common than the former, and occurs in well-defined crystals, in irregular grains, and in segregated granular masses. It is known in large bedded deposits of platy structure in Quebec and elsewhere, and as black sands from the disintegration of igneous rocks.

Associations: iron ores, pyroxenes, amphiboles, plagioclase, biotite.

Rocks: mainly in basic igneous rocks, but in many others.

Alteration: to a dull grayish-white substance known as leucoxene, and closely related to titanite.

Economic: Titanium finds many uses in commerce, but it is obtained mainly from rutile. As an ore of iron ilmenite is not in favor, owing to the difficulty of smelting it.

IRON MINERALS NOT IMPORTANT AS ORES OF IRON. MANY OF THEM ARE VALUABLE FOR OTHER PURPOSES

NATIVE IRON: No deposits of commercial importance are known. It occurs in grains in basalts and other very basic rocks, and occasionally in detached masses of considerable size, which are believed by many to be of meteoric origin.

AWARUITE is a nickeliferous native iron found in the gravels of the Gorge River, New Zealand.

JOSEPHINITE is a nickel-iron (Fe_2Ni_5) occurring in stream gravels in Oregon.

METEORIC IRON, METALLIC METEORITE, is an alloy of iron and nickel in which the nickel generally ranges from 5 to 10 per cent.

PYRITE: Sulphide of iron, FeS_2; sulphur 53.4 per cent, iron 46.6 per cent.

Color: pale brass-yellow.

Luster: metallic.

Crystallization: isometric; cubes, pyritohedrons and octahedrons.

Cleavage: indistinct.

Fracture: smooth, granular, conchoidal and uneven.

Hardness: 6—6.5.

Streak: greenish-black to brownish-black.

Specific gravity: 4.95—5.1.

Occurs: in rocks of all ages and varieties. It is a common gangue of gold and silver ores. Deposits of massive pyrite occur in Massachusetts, Virginia, New York and Georgia.

Alteration: oxidizes to iron sulphates, limonite, and occasionally to other oxides of iron.

Tests: Insoluble in hydrochloric acid, soluble in nitric acid. On coal gives sulphur which burns with a blue flame. Residue becomes magnetic. In closed tube a sublimate of sulphur and a magnetic residue.

Uses: It is rarely used for iron manufacture, but is much used as a source of sulphur and in making sulphuric acid. Cupriferous pyrite is an important copper ore in Montana, Arizona and Nevada. It is also used as a source of sulphite (of lime or magnesia) used in making (chemical) paper pulp.

MARCASITE, WHITE IRON PYRITE: A disulphide of iron, FeS_2; iron 46.6 per cent. Arsenic is sometimes present.

Color: pale bronze-yellow, but tarnishes to darker shades.

Luster: metallic; tarnishes rapidly.

Diaphaneity: opaque.

Crystallization: orthorhombic; tabular and pyramidal forms.

Cleavage: prismatic, rather good.

Fracture: uneven. Brittle.

Hardness: 6—6.5.

Streak: grayish or brownish-black.

Specific gravity: 4.85—4.9.

Occurrence: single crystals, star-shaped twins, massive stalactites, globular and kidney-shaped masses, spear and crest-like forms.

Associations: galena, pyrite, sphalerite, and other sulphide ores.

Rocks: It occurs in many mining areas with sulphide ores.

Tests: same as pyrite. Weathers and decomposes rapidly.

Alteration: Breaks up into white hydrous sulphates and finally oxidizes into limonite and hematite.

Remarks: Distinguished from pyrite and pyrrhotite by crystal form and mode of occurrence.

PYRRHOTITE: Magnetic pyrite, a sulphide of iron; often carrying nickel, $Fe_{11}S_{12}$, but varying from Fe_5S_6 to $Fe_{16}S_{17}$; iron about 61.6 per cent.

Color: bronze-yellow to copper-red.

Luster: metallic to dull; tarnishes readily.

Crystallization: hexagonal; crystals rare. Ore is usually granular massive.

Cleavage: parting sometimes distinct.

Fracture: uneven to subconchoidal. Brittle.

Hardness: 3.5—4.5.

Streak: dark grayish to greenish-black.

Specific gravity: 4.58—4.64.

Magnetism: weakly to strongly magnetic.

Occurs: igneous and metamorphic rocks, commonly in segregated masses.

Tests: On coal in R.F. fuses to black magnetic mass; in O.F. forms red oxide. Gives hydrogen sulphide when dissolved in hydrochloric acid. In open tube gives sulphur fumes.

Remarks: It is commonly nickel-bearing, and is the most important ore of nickel. It is sometimes copper-bearing.

LÖLLINGITE is a diarsenide of iron, $FeAs_2$, grading into LEUCOPYRITE, Fe_3As_4, and ARSENOPYRITE, FeAsS. It is a silver-white to steel-gray mineral, having a metallic luster, a grayish-black streak, a hardness of 5—5.5, and a specific gravity of 7.0—7.4. It occurs in Gunnison County.

ARSENOPYRITE, MISPICKEL, ARSENICAL PYRITES: A sulpharsenide of iron, FeAsS, or $FeS_2.FeAs_2$; iron 34.3, arsenic 46 per cent.

Color: silver-white to steel-gray.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: orthorhombic; crystals often flattened vertically. Twins in the form of crosses and stars are common.

Cleavage: uneven.

Tenacity: brittle.

Hardness: 5.5—6.

Streak: dark grayish-black.

Specific gravity: 5.9—6.2.

Occurrence: in crystals, grains, and massive in crystalline rocks, and in metalliferous veins.

Associations: ores of silver, lead, tin, nickel and cobalt; also with pyrite, chalcopyrite and sphalerite.

Tests: In closed tube gives first a red sublimate of arsenic sulphide, then a black mirror of metallic arsenic. In open tube gives fumes of sulphur and white arsenic trioxide, As_2O_3. Nitric acid decomposes it and separates sulphur. On coal in O.F. gives coating of arsenic trioxide, As_2O_3, and in R.F. a magnetic globule.

Colorado localities: in most of the camps where pyrite is a gangue mineral, as at Silverton, Telluride, Central City, etc.

Uses: as a source of arsenic, in the form of arsenic trioxide, As_2O_3, the white arsenic of commerce.

MARTITE is the sesquioxide of iron, Fe_2O_3, occurring in isometric crystals, which are probably pseudomorphs after magnetite or pyrite.

Color: iron-black.

Luster: submetallic.

Crystallization: isometric; octahedrons and dodecahedrons.

Parting: octahedral.

Fracture: conchoidal. Brittle.

Hardness: 6—7.

Specific gravity: 4.8—5.3.

Streak: reddish-brown to purplish-brown.

Magnetism: very weak or wanting.

Economic: not found in commercial quantity.

TRIPLITE is chiefly a phosphate of iron and manganese with calcium and magnesium. It is a brown to almost black mineral, of submetallic to resinous luster, almost opaque, having one good and one poor cleavage at right angles. It occurs in imperfectly crystalline masses, rarely in crystals.

Hardness: 4—5.5.

Specific gravity: 3.44—3.8.

Streak: yellowish-gray or brown.

Tests: Fuses easily to black magnetic globule; moistened with sulphuric acid gives blue-green phosphorus flame. With soda gives blue-green mass (manganese).

VIVIANITE, BLUE IRON EARTH: A hydrous ferrous phosphate, $Fe_3P_2O_8.8H_2O$.

Color: colorless when perfectly fresh, blue to green after exposure.

Luster: pearly to vitreous.

Diaphaneity: transparent to translucent, but opaque after long exposure.

Crystallization: monoclinic; prisms, often in diverging groups. Kidney-like and globular masses are found bedded in clay, etc.

Cleavage: basal, highly perfect.

Fracture: fibrous.

Tenacity: flexible in thin plates; sectile.

Hardness: 1.5—2.

Streak: colorless to pale blue, changing on exposure to indigo and brown.

Specific gravity: 2.58—2.68.

Occurrence: in seams and veins, and in the soft mud of water-courses in certain ore deposits. Often in cavities of fossils or buried bones.

Associations: pyrite, pyrrhotite, marcasite, ores of lead, copper and tin.

Tests: In closed tube yields water, whitens, exfoliates and crumbles. B.B. fuses very easily to dark magnetic globule and coloring the flame bluish-green (phosphorus). Gives common reactions for iron. Soluble in hydrochloric acid.

Colorado localities: several Leadville mines.

SCORODITE is a hydrous arsenate of iron, $Fe_2O_3.As_2O_5.4H_2O$. It is a pale, translucent, leek-green or liver-brown mineral of vitreous to subresinous luster, poor cleavage, uneven fracture, a hardness of 3.5—4, a specific gravity of 3.1—3.3, and a white streak. It occurs in frost-like and earthy crusts and coatings, mainly as an alteration product from minerals carrying iron and arsenic, but from various arsenical copper ores where iron minerals are present. In closed tube yields water and turns yellow. B.B. fuses easily, giving the blue arsenic flame; on charcoal gives arsenic fumes and a magnetic slag. Soluble in hydrochloric acid.

PHARMACOSIDERITE: A hydrous arsenate of iron, perhaps $6FeAsO_4.2Fe(OH)_3.12H_2O$.

Color: various shades of green, yellowish-brown and honey-yellow.

Luster: adamantine to dull.

Diaphaneity: translucent.

Crystallization: isometric; cubes truncated by octahedrons.
Cleavage: one imperfect.
Fracture: uneven.
Tenacity: sectile.
Hardness: 2.5.
Streak: green to brown to pale yellow.
Specific gravity: 2.9—3.
Tests: B.B. fuses easily, coloring flame blue (arsenic). On coal gives arsenic fumes, and yields a black slag when fused with soda. In closed tube yields water and changes color.

MELANTERITE, COPPERAS: A hydrous ferrous sulphate, $FeSO_4.7H_2O$, occurring in fine, fibrous, frost-like masses, stalactites and concretions—rarely massive.

Color: white and various shades of green, becoming yellowish on exposure.
Luster: vitreous.
Diaphaneity: translucent.
Taste: sweet, astringent.
Hardness: 2.
Specific gravity: 1.89—1.9.
Occurs: on walls and timbers of mines where pyrite or marcasite is decomposing.

COPIAPITE is a basic ferric sulphate, $2Fe_2O_3.5SO_3.18H_2O$, of sulphur-yellow color, pearly luster, occurring as crusts of crystalline scales or grains and sometimes massive. It has a hardness of 2.5, and a specific gravity of 2.1. It is soluble in water, and is decomposed by boiling water. On charcoal it becomes magnetic, and with fluxes reacts for iron.

CHROMIUM AND CHROMIUM MINERALS

USES: The principal use of the metal is in the form of the alloy ferrochromium, which is added to steels to produce chromium steel, chromium-nickel steel, chromium-tungsten steel, chromium-manganese steel and chromium-molybdenum steel. Chromium gives great hardness and resistance to impact. The hardness is modified by annealing. Chromium-tungsten steel is used for high-speed cutting tools. Chromite mixed with coal tar and molded into refractory brick is being used for furnace linings. Some chromite bricks contain kaolin, bauxite and milk of lime, etc. Chromite bricks and basic magnesite bricks are replacing acid bricks and highly aluminous silica bricks in furnaces used for copper, lead and antimony smelting. Chromium salts are used for paints, dyes, mordants, oxidizing agents, and for tanning. The salts used for paint materials are: chromic oxide, hydrous chromic oxide and chromium phosphate (green); lead chromate and potassium chromate (yellow, red and orange). Chrome yellow, chrome orange and chrome green are used as dyes. Many chromium salts are used as mordants in dyeing and printing cotton, linen and wool. The chief are: sulphates, nitrates, acetates, bichromates, fluoride and chrome alum.

Potassium bichromate is used as an oxidizing agent in dyeing, and making coal-tar dyes. It is also used to bleach oils and fats.

In tanning, various chromium salts are used.

CHROMIUM ORE

CHROMITE: Oxide of iron and chromium, $FeCr_2O_4$ or $FeO.Cr_2O_3$; chromium trioxide, Cr_2O_3, 68 per cent, or chromium 46.66 per cent.

Color: iron-black to brownish-black to yellowish-red.
Luster: submetallic to metallic.
Diaphaneity: weakly translucent to opaque.
Crystallization: isometric; octahedrons.
Cleavage: none; platy parting occurs.
Fracture: uneven.
Tenacity: brittle.
Hardness: 5.5.
Streak: brown.
Specific gravity: 4.32—4.57.
Occurs: mainly massive to fine or coarse granular.
Associations: generally with serpentine.
Tests: Almost infusible, but edges rounded in R.F. and becomes weakly magnetic. With borax and salt of phosphorus gives beads reacting for iron when hot, but chrome-green when cold. Insoluble in acids. Decomposed by fusion with potassium or sodium bisulphate. With soda and niter fuses on platinum to mass which is chrome-yellow when cold.

CROCOITE is described elsewhere.

CHROMIUM MINERALS NOT DESCRIBED. Daubreelite, Knoxvillite, Redingtonite, none of which occur in commercial quantity.

MANGANESE AND MANGANESE MINERALS

USES: The most important use of manganese is in the steel industry. In steel-making spiegeleisen and ferromanganese—alloys of iron and manganese—are used: (a) to remove oxygen, and to remove or counteract the effects of sulphur and phosphorus; (b) to restore to steel the necessary carbon after it has been removed in the first part of the steel-making process; (c) to increase the toughness, hardness and wearing qualities of steels for special purposes. Alloys of manganese with aluminum, copper, lead, magnesium, silicon, tin and zinc are made; and those with aluminum and copper have magnetic properties which may make them very important commercially. The alloy with silicon is used in steel manufacture. Manganiferous iron ore is used to some extent as a flux in smelting silver, copper and lead. Manganese oxide is used as an oxidizer: (a) in the manufacture of chlorine and bromine; (b) in coloring and decolorizing glass; (c) in dryers for paints and varnishes; (d) in the Leclanche battery and dry cells (Pyrolusite is used for this purpose); (e) in the manganate and permanganate disinfectants. Manganese is used as a coloring agent in calico printing and dyeing; in glass, brick and pottery manufacture; in violet and green pigments. Certain salts of manganese are used in medicine.

MANGANESE ORES

PYROLUSITE: Manganese dioxide, MnO_2; commonly containing a little water.

Color: iron black to dark steel-gray, often bluish-black.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: orthorhombic; tabular and prismatic—probably pseudomorphs after manganite and polianite.

Cleavage: one, sometimes two, good cleavages, but obscured by the softness of the mineral.

Fracture: uneven, often slightly splintery.

Tenacity: brittle and crumbling.

Hardness: 2—2.5.

Streak: black to bluish-black.

Specific gravity: 4.73—4.86.

Occurrence: columnar, often radiating, reniform fibrous crusts or coats; also massive and fine granular.

Associations: psilomelane, manganite, limonite, quartz.

Tests: Infusible. Yields oxygen when heated on charcoal;

yields chlorine when treated with hydrochloric acid. With soda gives bluish-green mass. With borax gives amethyst-colored bead in O.F., becoming colorless in R.F.

Remarks: It is probably an altered form of manganite and psilomelane.

Economic: ore of manganese in Vermont, Virginia, Arkansas, and elsewhere.

PSILOMELANE, BLACK HEMATITE: Composition doubtful, owing to impurities, but is probably a hydrous manganese manganate, H_4MnO_5, in which barium or potassium may replace part of the manganese. Manganese about 39.5 per cent.

Color: iron-black to dark metallic gray.

Luster: submetallic to dull earthy.

Diaphaneity: opaque.

Crystallization: never crystallized.

Cleavage: none.

Fracture: commonly rather smooth, sometimes subconchoidal.

Tenacity: brittle.

Hardness: 5—6.

Streak: brownish-black, shining.

Specific gravity: 3.7—4.7.

Occurrence: massive and botryoidal or kidney-shaped; stalactitic; often in layers with pyrolusite.

Associations: other manganese minerals and frequently iron ores.

Tests: Infusible. Heated in closed tube gives up oxygen and usually water, with soda gives bluish-green mass. Soluble in hydrochloric acid and evolves chlorine.

Differences: harder than pyrolusite; limonite has brown to yellow streak.

Economic: valuable ore of manganese. Used in manufacture of chlorine, oxygen, spiegeleisen, decolorizing and coloring glass, oxidizing agent in varnishes and linseed oil.

Colorado: not found in quantity in Colorado, although the manganiferous ores of Leadville contain it.

Localities: Crimera, Va.; Cartersville, Ga.; Batesville, Ark.; at various points in Vermont, North Carolina and California.

MANGANITE: Hydrous sesquioxide of manganese, $Mn_2O_3.H_2O$ or $MnO(OH)$; manganese 62.4 per cent.

Color: steel-gray to iron-black.

Luster: submetallic.

Diaphaneity: opaque.

Crystallization: orthorhombic; prismatic crystals with striated faces; often in groups with rounded cross-sections.

Cleavage: two perfect.

Fracture: uneven.

Tenacity: brittle.

Hardness: 4.

Streak: reddish-brown to nearly black.

Specific gravity: 4.2—4.6.

Occurrence: often by deposition from water.

Associations: other ores of manganese, and ores of iron.

Tests: Much water in closed tube, otherwise like pyrolusite, but gives less oxygen.

Remarks: Alters to other manganese minerals.

Colorado: various localities, but rarely in large quantity. Crystals found at Devils Head, Douglas County.

Economic: ore of manganese; see psilomelane.

BRAUNITE: Mainly manganese sesquioxide, but generally contains manganese silicate, $3Mn_2O_3.MnSiO_3$; manganese about 62 per cent.

Color: brownish-black to steel-gray.

Luster: submetallic.

Diaphaneity: opaque.

Crystallization: tetragonal in forms approaching octahedrons.

Cleavage: one perfect.

Fracture: subconchoidal to uneven.

Tenacity: brittle.

Hardness: 6—6.5.

Streak: brownish-black.

Specific gravity: 4.75—4.82.

Occurrence: frequently in veins and crusts and in irregular granular masses.

Associations: other manganese ores.

Tests: Similar to psilomelane, but generally leaves gelatinous silica.

Economic: ore of manganese, much mined in India and in Europe.

Colorado: not known in commercial quantity.

RHODOCHROSITE, DIALOGITE: Carbonate of manganese, $MnCO_3$; manganese 47.7 per cent.

Color: pink to rose to brownish-red.

Luster: vitreous to pearly.

Diaphaneity: transparent to subtranslucent.

Crystallization: hexagonal; crystals rare, except rhombohedrons.

Cleavage: perfect, parallel to rhombohedrons.

Fracture: uneven.

Tenacity: brittle.

Hardness: 3.5—4.5.

Streak: white.

Specific gravity: 3.45—3.6.

Occurrence: commonly in silver, silver-lead and copper veins, often as crusts and rounded and globular masses.

Associations: silver, lead, copper and gold ores, and other manganese minerals.

Tests: Before blowpipe infusible, decrepitates strongly, changes to gray or brown or black. Soluble in hot hydrochloric acid with effervescence. Gives usual manganese tests.

Colorado: many mines in San Juan area, Boulder, Lake and other counties.

ALABANDITE, MANGANBLENDE, sulphide of manganese; MnS; manganese 63.1 per cent. It is an iron-black to brownish-black mineral of submetallic luster, usually occurring in granular masses, but occasionally in cubes and dodecahedrons, having a perfect cubic cleavage. The hardness is 3.5—4, and the streak is green. It gives the usual reactions for manganese, yields sulphur fumes in the open tube, and is soluble (with evolution of hydrogen sulphide) in hydrochloric acid. It occurs at various points in Colorado, but chiefly on the Snake River, Summit County.

MANGANESE MINERALS LESS IMPORTANT AS ORES

POLIANITE is manganese dioxide MnO_2; commonly in groups and bunches of needle-like crystals of light steel or iron-gray. It is harder than pyrolusite and is anhydrous.

WAD is a hydrous earthy to compact, dark-brown to black mixture of oxides of manganese, and frequently oxides of other metals, such as cobalt, lead, iron, copper. It varies in hardness from 1 to 6. It is sometimes loose and dusty.

ASBOLITE is a wad containing oxide of cobalt, sometimes up to 30 per cent or over.

LAMPADITE or CUPROUS MANGANESE is a wad containing 4 to 18 per cent of oxide of copper, and often oxide of cobalt.

HAUSMANNITE: Mn_3O_4 or $Mn_2O_3.MnO$; occurs in tetragonal octahedrons and twins and granular masses. It has a hardness of 5—5.5, brownish color and streak, a submetallic luster, and a specific gravity of 4.85. Not important as an ore.

MANGANESE-BEARING MINERALS NOT DESCRIBED: Hauerite, Manganosite, Bixbyite, Pyrochroite.

MOLYBDENUM AND MOLYBDENUM MINERALS

USES: Metallic molybdenum is used in the manufacture of tool steel and other special steel, but, though its use is increasing, it has not yet proved so satisfactory as tungsten. Molybdenum wire is used as a support for the filament in certain incandescent lamps.

Ammonium molybdate is used in the determination of phosphorus in iron; in fireproofing materials; as a disinfectant and germicide. Sodium molybdate is used as a coloring agent in pottery making, and in silk and woolen dyeing. Molybdenum tannate is used in coloring leather. "Molybdenum indigo," Mo_5O_7, is used in coloring rubber.

MOLYBDENUM ORES AND MINERALS

MOLYBDENITE: Molybdenum sulphide, MoS_2; molybdenum 60.0 per cent.

Color: lead-gray.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: hexagonal; tabular or short prismatic crystals.

Cleavage: one perfect, yielding flexible flakes.

Tenacity: sectile.

Hardness: 1—1.5.

Streak: lead-gray metallic, bluish-gray on paper.

Specific gravity: 4.7—4.8.

Occurrence: in foliated or scaly masses and fine granular. In grains and masses in granite, gneiss, zircon syenite, granular limestone, etc.

Tests: Infusible, but at high heat gives flame yellowish-green color. On charcoal gives sulphur fumes and slight sublimate, yellow hot and white cold, and deep blue when flashed with reducing flame. Soluble in strong nitric. Gives blue solution with sulphuric acid.

Colorado: Molybdenite has been mined a few miles west of Empire, and promising deposits are known in Pitkin County and Summit, both north and south of Breckenridge and near Fremont Pass. Encouraging discoveries have been made near Silverton and at other points in the San Juan. High grade ore in small quantity is reported near Salida and farther northwest near Monarch. Samples of the San Juan and Monarch ores show molybdite also.

Economic: molybdenum steel and molybdenum salts.

WULFENITE: A molybdate of lead, $PbMoO_4$ or $PbO.MoO_3$; lead 56.3 per cent, molybdenum trioxide 39.3 per cent.

Color: wax-yellow to orange, pale green, red and yellowish-gray.

Luster: resinous to adamantine.

Diaphaneity: translucent.

Crystallization: tetragonal. Thin, square, tabular crystals are commonest, but octahedral and prismatic forms occur.

Cleavage: one good, two less distinct.

Fracture: subconchoidal. Brittle.

Hardness: 2.75—3.

Streak: white.

Specific gravity: 6.7—7.

Associations: other lead minerals, especially pyromorphite, and vanadinite.

Occurs: crystals, more or less perfect, crystal crusts, massive granular.

Tests: On coal fuses easily; with soda yields lead. With phosphorus salt gives yellowish-green glass O.F., dark green R.F. Strong hydrochloric acid gives green solution, which, when much diluted and stirred up with tin, becomes deep blue and finally brown.

MOLYBDITE, MOLYBDIC OCHRE, $Fe_2O_3.3MoO_3.7\frac{1}{2}H_2O$; occurs as an earthy yellow powder or in hair-like crystals of pale-yellow color. It has a dull luster, a straw-yellow streak, a hardness of 1—2, and a specific gravity of 4.5. It fuses on charcoal, yielding crystals which are yellow when cold. It is not important.

It occurs in the Monarch district, Chaffee County, and in the San Juan.

POWELLITE is a calcium molybdate, $CaMoO_4$; molybdenum trioxide 82.0 per cent. It is a greenish-yellow, subtransparent, resinous mineral having no cleavage, an uneven fracture, a hardness of 3.5, a specific gravity of 4.52. *Tests*: Fuses with difficulty to a gray mass; reacts for molybdenum with salt of phosphorus; decomposed by nitric and hydrochloric acids.

NICKEL AND COBALT AND THEIR MINERALS

USES OF NICKEL: By far the most important use of nickel is in the manufacture of the various nickel steels, which include nickel steel, chrome-nickel steel, tungsten-nickel steel, molybdenum-nickel steel, and others. The nickel and other steel-hardening metals are added to the molten steel in the form of the alloys: ferro-nickel, chrome-nickel, molybdenum-nickel, etc. The nickel gives greater hardness, toughness, elasticity and tensile strength to the steel. A common nickel steel, the Krupp steel, contains 3.5 per cent nickel, 1.5 per cent chromium and about 0.25 per cent carbon.

The uses of nickel steel are for armor plate, gun shields, turrets, steel rails, heavy forgings, marine engines, wire cables, electric apparatus, etc. For a number of these uses the steel contains one of the other steel-hardening metals in addition to the nickel. The metal is also used for plating other metals and for ornamental purposes.

Monel metal is a remarkably useful alloy of nickel, copper and iron, in about the proportions: nickel 68 per cent, copper 26.25 per cent, iron 3.25 per cent; with some manganese and carbon. Its strength, workability, resistance to corrosion, and wearing qualities make it eminently suitable for propeller wheels, marine pumps, mine pumps, mine screens, roofing, and many other purposes. Some alloys of nickel and aluminum have great strength and wearing qualities. The five-cent coin is an alloy of nickel and copper. German silver contains copper, zinc and nickel.

The salts of nickel are not widely used.

USES OF COBALT: The oxide of cobalt is used for coloring glass and porcelain. Smalt blue is a pigment made by coloring glass and other artificial silicate substances, and pulverizing the product. Cobalt blue is another cobalt pigment. Cobalt salts and cobalt test papers are used in chemical laboratories. Attempts have been made to use cobalt in the steel industry, and very promising results have been obtained.

NICKEL ORES AND MINERALS

GARNIERITE, Noumeite: A hydrated silicate of magnesium and nickel, perhaps $H_2(Ni,Mg)SiO_4+H_2O$. The percentage of nickel varies from 20 to 45.

Color: pale apple-green to bright green.
Luster: varnish-like to dull.
Diaphaneity: opaque.
Crystallization: non-crystalline.
Cleavage: none.
Fracture: smooth, subconchoidal.
Tenacity: brittle, friable.
Hardness: 2—3; also soft amorphous.
Streak: pale green to white.
Specific gravity: 2.27—2.8.
Occurs: irregular masses, often showing concretion-like forms of different color.
Rocks: mainly serpentine.
Tests: Infusible, decrepitates; yields water in closed tube. Colors borax bead red. Partially soluble in hydrochloric and nitric acids.
Remarks: Found in New Caledonia in commercial amount; in United States in small deposits in Douglas County, Oregon, and in North Carolina.

NICKELIFEROUS PYRRHOTITE is described under iron. It is the chief ore of nickel at Sudbury, Ontario.

MILLERITE, Capillary Pyrites: Nickel sulphide, NiS; nickel 64.7 per cent.

Color: brass-yellow to bronze-yellow.
Luster: metallic.
Diaphaneity: opaque.
Crystallization: hexagonal. Commonly in slender or capillary crystals, often radiating.
Fracture: uneven.
Tenacity: brittle.
Hardness: 3—3.5.
Streak: greenish-black.
Specific gravity: 5.3—5.65.

Occurs: commonly in radiating groups of slender crystals forming crusts and coatings.

Tests: In the open tube gives sulphur fumes. B.B. on coal fuses to a globule. In R.F. the mineral forms a coherent mass, attractable by the magnet. Roasted mineral gives with borax and salt of phosphorus a violet bead O.F., becoming gray in R.F. from reduced metallic nickel.

PENTLANDITE is a sulphide of iron and nickel, nearly 2FeS.NiS; nickel 22 per cent. It is a light bronze-yellow mineral of metallic luster, light bronze-brown streak, octahedral cleavage, a hardness of 3.5—4, and a specific gravity of 4.6. It is an important mineral in the Sudbury nickel deposits of Ontario.

Tests: The common nickel and iron reactions. The powdered mineral roasted on charcoal gives, with the fluxes, reactions for iron and nickel.

NICCOLITE, COPPER NICKEL: Nickel arsenide, NiAs; nickel 43.9 per cent; arsenic 56.1 per cent.

Color: pale copper-red.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: hexagonal; crystals are rare.

Cleavage: none.

Fracture: smooth to uneven.

Tenacity: brittle.

Hardness: 5—5.5.

Streak: pale brownish-black.

Specific gravity: 7.33—7.67.

Occurs: massive, very fine granular, also columnar reticulated.

Associations: Accompanies other nickel ores, cobalt, silver, and copper ores, such as smaltite, cobaltite, native silver, argentite, millerite, chloanthite, chalcopyrite.

Tests: In the closed tube gives a faint white crystalline sublimate of arsenic trioxide, As_2O_3; in the open tube, a sublimate of arsenic trioxide, the assay changing to yellowish-green. On coal fuses with white fumes to a magnetic globule which reacts for iron, cobalt and nickel. Soluble in strong nitric acid and aqua regia.

GERSDORFFITE is a sulpharsenide of nickel, $NiS.NiAs_2$, usually carrying both iron and cobalt. It is a silver-white to steel-gray mineral of metallic luster, a hardness of 5.5, and a specific gravity of 5.6—6.2. It usually occurs massive. *Tests*: B.B. on charcoal gives sulphur and arsenic fumes, and fuses to a globule which with borax glass (fused borax) gives an iron reaction. When more borax glass is added, cobalt and nickel reactions are obtained. Dissolved by warm nitric acid, forming a green solution.

ZARATITE, EMERALD NICKEL, $NiCO_3.2Ni(OH)_2+4H_2O$, occurs as emerald-green mammillary crusts and in compact masses. Reacts for cobalt and nickel.

ANNABERGITE is a hydrous nickel arsenate, $Ni_3As_2O_8.8H_2O$, with a little cobalt oxide. It is a soft, apple-green mineral, occurring in needle-like crystals forming crusts and masses, and in scattered grains. B.B. fuses easily, and on charcoal gives arsenic odor and yields a metallic button. A part of the bead dissolved in borax glass gives the cobalt-blue, and on further heating the violet or reddish-brown of nickel. In R.F. metallic nickel is formed and the bead turns gray. *Colorado localities*: The Gem and other mines near Silver Cliff, with niccolite.

GENTHITE, a hydrous magnesium-nickel silicate, $2NiO.2MgO.3SiO_2.6H_2O$, of pale apple-green or yellowish color, resinous luster, greenish streak. It occurs in amorphous incrustating masses.

SMALTITE—CHLOANTHITE: The two minerals grade into one another. Smaltite is essentially a diarsenide of cobalt $CoAs_2$; cobalt 28.2 per cent. Nickel is almost always, and iron commonly, present. Chloanthite is essentially a diarsenide of nickel, $NiAs_2$; nickel 28.1 per cent. Cobalt is almost always, and iron commonly, present.

Color: tin-white to steel-gray.
Luster: metallic.
Diaphaneity: opaque.
Crystallization: isometric, in distorted forms; massive.
Fracture: granular and uneven.
Tenacity: brittle.
Hardness: 5.5—6.
Streak: grayish-black.
Specific gravity: 6.4—6.6.
Occurs: commonly massive; also in reticulated forms. In veins.
Associations: ores of cobalt or nickel, and silver and copper.
Tests: In closed tube a sublimate of arsenic. In the open tube, a sublimate of arsenic trioxide As_2O_3. On charcoal gives arsenic odor, and fuses to globule, which, treated with

successive proportions of borax glass, reacts for iron, cobalt and nickel. Soluble in nitric acid, yielding a red to green solution.

MAUCHERITE: A tetranickel-triarsenide, Ni_4As_3; nickel 51.1 per cent. arsenic 48.9 per cent.

Color: silver-white with a touch of red, tarnishing very quickly to gray and ultimately to tints resembling those of bornite.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: tetragonal; thin quadratic plates.

Cleavage: imperfect.

Fracture: uneven.

Tenacity: brittle.

Hardness: 5—5.5.

Streak: brownish-black to black.

Specific gravity: 7.8—7.9.

Occurs: radiating fibrous masses built up into arborescent. botryoidal forms. Associated with niccolite, smaltite, native bismuth in the mines of Cobalt, Ontario, and in various places in Europe.

Tests: Fuses at 2, soluble in nitric acid yielding nitrous fumes. In open tube deposits arsenious oxide. On charcoal gives white arsenic coating. With bismuth flux gives the arsenic coating.

Economic: Probably a somewhat common ore of nickel mistaken for other ores, such as chloanthite.

COBALT ORES AND MINERALS

COBALTITE, COBALTINE, COBALT GLANCE: A sulpharsenide of cobalt, CoAsS; cobalt 35.5 per cent.

Color: silver-white. inclined to red; also steel-gray.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: isometric-pyritohedral. Cubes, or pyritohedrons, or combinations resembling forms of pyrite.

Cleavage: good.

Fracture: uneven.

Tenacity: brittle.

Hardness: 5.5.

Streak: grayish-black.

Specific gravity: 6—6.3.

Occurs: in veins with ores of cobalt and nickel, silver and copper.

Tests: In closed tube unaltered. In open tube gives sulphur fumes and sublimate of arsenic trioxide, As_2O_3. B.B. on coal yields sulphur and arsenic, and fuses to a metallic globule. With borax gives cobalt-blue color. Soluble in nitric acid with separation of sulphur.

ERYTHRITE, COBALT BLOOM: A hydrous cobalt arsenate, $Co_3As_2O_8+8H_2O$, or $3CoO.As_2O_5+8H_2O$; cobalt 29.33 per cent, arsenic 35.05 per cent.

Color: crimson to peach-red, to gray.

Luster: adamantine to vitreous to pearly.

Diaphaneity: transparent to weakly translucent.

Crystallization: monoclinic, prismatic.

Cleavage: one perfect.

Tenacity: sectile.

Hardness: 1.5—2.5.

Streak: paler than the color of the mineral.

Specific gravity: 2.95.

Occurs: mainly in globular and reniform shapes with drusy surfaces and columnar structure; also as soft earthy, powdery crusts.

Tests: Closed tube gives water and turns bluish; at higher heat gives off arsenic trioxide As_2O_3, which forms crystals on the cool glass. B.B. in forceps fuses at 2 to a gray bead, coloring the flame a light blue (arsenic); on coal gives arsenic odor, and fuses to dark-gray arsenide, which with borax gives the deep cobalt-blue. Soluble in hydrochloric acid to rose-red solution.

LINNAEITE is a sulphide of cobalt, Co_3S_4, or $CoS.Co_2S_3$, with some nickel. It is a pale steel-gray mineral of metallic luster, but tarnishing to copper-red, having a hardness of 5.5, and a specific gravity of 4.8—5. It occurs in octahedrons and massive.

Economic: an ore of nickel.

GLAUCODOT is a sulpharsenide of cobalt and iron, $(Co, Fe)AsS$, or $(Co, Fe)S_2.(Co, Fe)As_2$. The percentage of cobalt varies. It is isomorphous with arsenopyrite. It is an opaque grayish or tin-white, metallic mineral having a fair cleavage, an uneven fracture, a hardness of 5, a specific gravity of 5.9—6.01. It reacts for arsenic, sulphur, iron and cobalt.

LAMPADITE and ASBOLITE are described with manganese minerals.

NICKEL AND COBALT MINERALS DESCRIBED ELSEWHERE ARE:

Nickeliferous pyrrhotite and meteoric iron.

NICKEL AND COBALT MINERALS NOT DESCRIBED: Breithauptite, Melonite, Ullmanite, Morenosite, Rammelsbergite.

TITANIUM AND TITANIUM MINERALS

USES: The principal use of titanium is in the purification of steel, by the removal of oxygen and nitrogen. The removal of these elements, however, allows the steel to take on modified physical characters which are highly important in connection with the wearing qualities of the steel. Many metallurgists believe that titanium is beneficial to steel in other ways, particularly in increasing the elasticity. Steel purified by titanium is used for railway rails, rolls for shaping steel, steel castings, gears, tires, dies, stamp heads, propeller shafts, automobile frames, tools, ingot molds, car wheels, etc. Titanium is also used to improve cast iron in the same way. The titanium is added in the form of an alloy, ferrotitanium, as in the case of other steel-improving metals. Titanium is also used in the electrodes of arc lights.

Salts of titanium find a number of uses: The chloride, the sulphate and other salts are used as mordants and coloring agents.

Rutile gives a soft yellow color to porcelain tile. Certain salts are used in fireworks, and titanium ferrocyanide is used in pigments.

Titanium is also used in the porcelain industry to give certain colors. The titanium ores produced in this country are mainly rutile and highly titaniferous iron ore.

RUTILE: Titanium dioxide, TiO_2; titanium 60.0 per cent.

Color: commonly reddish-brown to red and yellowish, bluish, violet and black.

Luster: metallic to adamantine.

Diaphaneity: transparent to opaque.

Crystallization: tetragonal; prisms vertically striated; knee-shaped twins and complex twins are common. It is occasionally massive.

Cleavage: two distinct.

Fracture: subconchoidal to uneven.

Tenacity: brittle.

Hardness: 6—6.5.

Streak: pale brown.

Specific gravity: 4.18—4.25.

Occurrence: It is found in a great variety of rocks, such as granites, gneisses, schists, slates, dolomites, and others. It is commonly in crystals. It is rarely found in large quantities.

Tests: B.B. infusible. With phosphorus salt gives a colorless bead which, when cooled from the reducing flame (inner flame), becomes violet. Sometimes the violet color comes only after bead is fused with tin on charcoal. Insoluble in acids, but soluble after fusion with soda. The acidulated solution boiled down with metallic tin gives a fine violet color.

NIGRINE is a black variety of rutile, carrying a considerable percentage of iron.

BROOKITE is an orthorhombic form of titanium dioxide, TiO_2, occurring only in crystals. It varies in color from yellowish-brown to red, reddish-black and black. The lighter-colored crystals are translucent, while the black ones are opaque, and the streak varies from uncolored to yellowish or grayish. The cleavage is poor, the fracture subconchoidal to uneven; hardness 5.5—6; specific gravity 3.87—4.01. The tests are the same as for rutile. It is not known in commercial quantities.

OCTAHEDRITE, ANATASE, is titanium dioxide, TiO_2; titanium 60.0 per cent.

Color: various shades of brown, passing into blue and black.

Luster: submetallic to adamantine, even resembling the diamond.

Diaphaneity: transparent to nearly opaque.

Crystallization: tetragonal crystals of octahedral habit, rarely prismatic.

Cleavage: two perfect.

Fracture: subconchoidal.

Tenacity: brittle.

Hardness: 5.5—6.

Streak: uncolored.

Specific gravity: 3.82—3.95.
Occurrence: generally in crystal form, along with quartz, chlorite, ilmenite, axinite, etc.
Tests: same as rutile.

ILMENITE, TITANIC IRON, is described elsewhere. This will prove to be the chief source of the metal in the future.

TUNGSTEN AND TUNGSTEN MINERALS

USES: The manufacture of tungsten steel takes by far the largest part of the tungsten produced. Tungsten steels are classed as:

1. *Simple tungsten steel*—an ordinary carbon steel to which about 6 per cent of tungsten has been added. This is used chiefly in the manufacture of permanent magnets for electric meters, magnetos of all kinds, and in certain scientific apparatus. A steel with 3 to 4 per cent tungsten is used as a tool steel for finishing purposes, but is not strictly a high speed steel and is not self-tempering. A simple tungsten steel is used in the tubes of cannon.

2. *Quaternary steels:* These contain another alloying metal besides the tungsten. The second metal may be chromium, vanadium, cobalt, or manganese. These steels are used chiefly for high-speed cutting tools, but to a limited extent for structural purposes.

3. *Complex steels*: These contain more than two alloyed metals. Most high-speed tool steels belong to this class. The three most important alloying elements are tungsten, which generally ranges between 16 and 20 per cent; chromium, ranging commonly between 3 and 5 per cent; and vanadium, ranging generally between 0.5 and 1.5 per cent. The latter limit is considered excessive by many makers. These rapid steels have the property of keeping a sharp cutting edge while heated to a temperature far above that which would destroy the cutting ability of a simple steel.

Tungsten steel is used to a limited extent in the making of armor plate, but probably not in the main mass of the plate.

METALLIC TUNGSTEN

Ductile, metallic tungsten has become a market commodity within the last three or four years.

A few of the many possible uses are as follows:

1. A substitute for platinum and platinum alloys as contact points in spark coils, voltage regulators, telegraph relays, resisters in electrical laboratory furnaces, and as targets in Roentgen tubes.

2. In the form of gauze it could be used for the separation of solids from acid liquors, as, for example, the removal of sludge from copper refining baths; the manufacture of acid-proof dishes and tubes.

3. In calibrating instruments and apparatus, such as standard weights, standard resistances, electrical meters, and many others.

4. Its chemical stability and resistance to change under atmospheric conditions make it suitable for many uses where delicate yet strong metallic wires, points and springs are needed, as in watch springs, pen points, drawing dies, cross hairs in telescopes and other optical instruments, galvanometer suspensions and the wires of musical instruments.

The ductile metal is now drawn through dies into wire of any desired size down to a diameter of 0.0002 inch (one-sixth the diameter of a fine human hair). (The dies for the finest wire consist of drilled diamonds.) As a consequence, the metallic tungsten wire filament for incandescent lamps has completely replaced the ''paste'' filaments described in the first issue of this Report, and the carbon filament is doomed. In 1913 the gas-filled incandescent tungsten lamp was placed on the market. This consists of a metallic, tungsten filament in a globe filled with nitrogen. This change reduces the consumption of current to about one-half watt per candle power, as compared with 1.25 watts per candle power for the vacuum lamp. The life of the filament is also prolonged because of the reduced rate of evaporation of the metallic tungsten in an atmosphere of nitrogen.

The light produced by the gas-filled lamp approaches day-light in whiteness.

It is estimated that the total American consumption of metallic tungsten for lamp filaments does not exceed two tons per year.

Many valuable alloys of tungsten are in use. Platinoid contains copper, zinc, nickel and tungsten. Wolfram-aluminum is an alloy of tungsten and aluminum. Partinium is a light and very strong alloy of tungsten and aluminum. An alloy containing tungsten, aluminum and copper is used for propeller blades. Minargent contains tungsten, nickel and copper. Sideraphite contains iron, nickel, aluminum, copper and tungsten. An alloy containing 73–75 per cent tungsten, 23–25 per cent nickel, a small amount of iron, silicon and carbon, is much used. Many alloys of tungsten with chromium, titanium, zirconium, columbium and tantalum are available.

An alloy containing 20 to 60 per cent tungsten and 80 to 40 per cent platinum is recommended for electrical contacts and for jewelry. Alloys of tungsten and thorium have been patented. The tensile strength of aluminum is increased by the addition of about 1 per cent of tungsten. Duralium is an alloy of tungsten and aluminum containing 2 to 3 per cent of tungsten. A new type metal contains; tungsten 10 parts, copper 10 parts and aluminum 80 parts.

Stellite, an alloy of cobalt and chromium, invented by Haynes, has been modified and greatly improved for certain purposes by the addition of tungsten. When the chromium is held at 15 per cent and tungsten added in amounts varying from 5 per cent to 40 per cent, the hardness and cutting qualities of tools formed from it are greatly increased. Tests indicate that it far surpasses the high-speed steels. (Alloys of Cobalt with Chromium and Other Metals, by Elwood Haynes, Bull. A. I. M. E., Feb., 1913, pp. 249-255.)

Sodium tungstate and barium tungstate are used in glass-coloring and pottery-glazing for the production of blue and yellow tints. Sodium paratungstate is used as a mordant in dyeing and calico-printing, and for fireproofing cloth. Various salts characterized by rich color tones are used in making stained papers, and others are used to weight silks. Tungsten bronzes of beautiful color and high luster are made from sodium tungstate and potassium tungstate. Calcium tungstate is used as a screen to make the X-rays visible.

TUNGSTEN MINERALS IMPORTANT AS ORES

THE WOLFRAMITE SERIES

The three dark-colored tungsten minerals, *hübnerite, wolframite* and *ferberite* form a series graduating from almost pure manganese tungstate at the one end to almost pure iron tungstate at the other. In the middle of the series are forms in which the manganese tungstate and the iron tungstate are present in almost equal amounts. Hess has proposed the following definitions for what he calls the wolframite series:

Ferberite: A monoclinic tungstate having, when pure, the composition $FeWO_4$. It may contain not more than 20 per cent of the hubnerite molecule, $MnWO_4$.

Hübnerite: A monoclinic manganese tungstate, having the composition $MnWO_4$. It may contain not more than 20 per cent of the ferberite molecule, $FeWO_4$.

Wolframite: A monoclinic mineral containing the ferberite molecule ($FeWO_4$) and the hübnerite ($MnWO_4$), in all proportions between 20 per cent $FeWO_4$ and 80 per cent $MnWO_4$, and 80 per cent $FeWo_4$ and 20 per cent $MnWO_4$.

WOLFRAMITE, WOLFRAM: A tungstate of iron and manganese, $(Fe,Mn)WO_4$; with FeO:MnO chiefly 4:1 and 2:3; tungsten trioxide, 76.4 to 76.5 per cent.

Color: dark grayish or brownish-black.

Luster: submetallic to metallic.

Diaphaneity: opaque.

Crystallization: monoclinic; tabular to prismatic, long-bladed forms, often divergent.

Cleavage: one very perfect.

Fracture: uneven.

Tenacity: very brittle, friable.

Hardness: 5—5.5.

Specific gravity: 7.2—7.5.

Streak: nearly black.

Occurs: often as crusts and druses, also massive, granular, both coarse and fine.

Associations: tin ores, tourmaline, fluorite, topaz, beryl, and other tungsten minerals, generally in quartz or highly silicious gangue.

Rocks: granites of various kinds, including pegmatite and greisen.

Tests: Fuses to a weakly magnetic globule. Soluble in strong hydrochloric acid, or *aqua regia* (one part nitric acid and three parts hydrochloric), with formation of a yellow powder which, when boiled with zinc or tin, forms a fine blue solution. Reacts for manganese with soda on platinum foil.

Remarks: It is sometimes pseudomorphic after scheelite, and sometimes alters to scheelite.

FERBERITE: A tungstate of iron, $FeWO_4$; tungsten trioxide, WO_3, 76.32 per cent. Manganese may replace a small part of the iron.

Color: black to blue-black to faint brownish-black.

Luster: submetallic to brilliant metallic on cleavage surfaces; submetallic on crystal faces and granular surfaces.

Diaphaneity: Weakly translucent in cleavage plates, but generally opaque.

Crystallization: monoclinic; chisel and spear-head forms, prisms and plates occur.

Cleavage: one, perfect.

Fracture: uneven.

Tenacity: very friable.

Hardness: 4.5—5.5.

Streak: gray-black to black to brownish-black.

Specific gravity: 7.2—7.5.

Occurs: in crystalline crusts, druses and vug-linings; also massive, fine granular.

Tests: same as for wolframite.

Remarks: Hübnerite, wolframite and ferberite form a series in which iron increases and manganese decreases. Ferberite is the ore of Boulder County, Colorado.

HÜBNERITE: A tungstate of manganese and iron, $(Mn,Fe)WO_4$, with manganese in excess of the iron; tungsten trioxide about 75 per cent.

Color: blackish-brown to seal-brown to hair-brown, occasionally blue-black.

Luster: submetallic to metallic and adamantine.

Diaphaneity: opaque to translucent.

Crystallization: monoclinic; tabular to prismatic, long-bladed forms, often divergent.

Cleavage: one perfect.

Fracture: uneven.

Tenacity: friable.

Hardness: 5—5.5.

Streak: grayish-black, dark reddish-brown to yellowish-brown to greenish-gray.

Specific gravity: 7.2—7.5.

Occurs: in same forms as wolframite, but radiating bladed forms are common.

Associations: same as wolframite.

Tests: same as for wolframite, but reacts more strongly for manganese.

SCHEELITE: A calcium tungstate, $CaWO_4$; tungsten trioxide, WO_3, 80 per cent. Molybdenum is often present.

Color: white, yellowish, brownish, greenish, reddish.

Luster: vitreous to adamantine.

Diaphaneity: transparent to translucent.

Crystallization: tetragonal; pyramidal and tabular forms predominate.

Cleavage: fair.

Fracture: uneven.

Tenacity: brittle.

Hardness: 4.5—5.

Streak: white.

Specific gravity: 5.9—6.1.

Occurs: imperfect crystals, massive, granular; also reniform and columnar.

Associations: cassiterite, topaz, fluorite, apatite, molybdenite, other tungsten ores.

Tests: Fuses with difficulty to a semi-transparent glass; soluble in hydrochloric acid, forming a yellow powder, which, when boiled with zinc or tin, gives a deep blue solution.

Remarks: It is sometimes pseudomorphous after wolframite, and sometimes alters to other tungsten minerals.

TUNGSTEN MINERALS NOT IMPORTANT AS ORES

STOLZITE, a tungstate of lead, $PbWO_4$; tungsten trioxide, WO_3, 51.0 per cent, lead 45.4 per cent.

Crystallization: tetragonal; pyramids often in aggregates.

Cleavage: two poor.

Fracture: Conchoidal to uneven. Brittle.

Hardness: 2.75—3.

Specific gravity: 7.87—8.13.

Luster: resinous to subadamantine.

Color: green, yellowish-gray, brown and red.

Streak: uncolored.

Diaphaneity: faintly translucent.

Tests: B.B. fuses easily to a crystalline, lustrous, metallic pearl; on coal with soda yields lead; decomposed by nitric acid, leaving yellow residue of tungsten trioxide. This boiled with tin or zinc gives a blue solution.

TUNGSTITE, TUNGSTIC OCHRE, WO_3, tungsten 79.3 per cent, is a bright-yellow or yellowish-green, soft earthy mineral resulting from the decomposition of wolframite, ferberite, scheelite, and other tungsten minerals.

Tests: B.B. on charcoal becomes black in inner flame, but does not fuse. With salt of phosphorus gives O.F. a colorless or yellowish bead, which in R.F., when cold, becomes a blue glass. Insoluble in acids.

Colorado: Boulder County mines in small quantity.

CUPROTUNGSTITE, a tungstate of copper, $CuWO_4$; also a tungstate of copper and calcium, $(Ca,Cu)WO_4$; tungstic acid variable, copper variable.

Color: various shades of green.

Luster: highly vitreous.

Crystallization: crystalline granular, and in crusts.

Cleavage: one distinct.

Hardness: 4.5—5.

Streak: greenish-gray to greenish-yellow.

Tests: B.B. fuses to black glass, giving flame the copper-green color. On charcoal blackens, fuses with swelling, forming a black slag containing particles of copper. Soluble in hydrochloric, with separation of yellow tungsten trioxide which may be tested as described under wolframite.

URANIUM AND VANADIUM AND THEIR MINERALS

USES OF URANIUM: Metallic uranium and uranium carbide are used in the steel industry to increase the toughness, hardness and elongation of steel for special purposes. Recent investigation has proved the value of uranium in the tool-steel industry, and it is highly probable that if a steady supply of ores can be assured, steels containing uranium will take a very prominent place among high-speed tool steels. It is also used in the mantles of incandescent gas lamps, with thoria, ceria and zirconia, and in filaments of electric lamps. Various uranium salts are used in iridescent glass and pottery glazes. The trioxide is used in porcelain-painting and calico-printing. Certain uranium salts are used in medicine, and others in chemical determinations.

The uranium minerals are radioactive, and they are the chief source of radium, helium, and other rare elements now eagerly studied. The most important sources of radium are carnotite and pitchblende.

Ore containing 3,000,000 ounces (roughly ninety-four tons) of metallic uranium would contain one ounce of radium. A ton of ore carrying one per cent of U_3O_8 would yield roughly one eleven-thousandth of an ounce of radium, or 11,000 tons of such ore would yield one ounce of radium.

USES OF VANADIUM: The most important use of vanadium is in the steel industry. It is said to improve the steel by the removal of oxygen and nitrogen, by the formation of a solid solution with the iron, and by the formation of beneficial carbides. The vanadium added amounts to about 0.35 per cent, of which 0.1 per cent is lost in removing the oxygen and nitrogen, and 0.25 per cent remains in the steel. It is commonly used with chromium or manganese, or both, or with these and nickel. Vanadium steel resists fatigue in a most remarkable manner. As a consequence it is very valuable where steel is under long continued stress and jar as in springs, axles, crank shafts, gears, and wheels. Many high speed tool steels contain from 0.50 to 1.0 per cent of vanadium.

The pentoxide, V_2O_5, is used as a catalytic agent in sulphuric acid manufacture. Several salts of vanadium are used in chemical processes, photography, glass and porcelain-coloring, dyeing silks and other fabrics, as an oxidizing agent, and in the reduction of organic compounds; in making certain bronzes, and permanent inks. Salts of vanadium are used in medicine.

URANIUM AND VANADIUM MINERALS IMPORTANT AS ORES

Uranium-bearing minerals are very numerous, but only a few are likely to be of any commercial value. A large number are secondary minerals after the more important ones. A full list will be found in the *Engineering and Mining Journal*, Volume 87, page 257, 1909, and in Bull. 70 of the U. S. Bureau of Mines, pp. 91-96.

URANINITE, PITCHBLENDE: Mainly a uranite of uranyl, (UO_2), lead, etc. It may contain calcium, zirconium, iron, copper, bismuth, the metals of the lanthanum and yttrium groups, and the gases nitrogen, helium, argon, etc. Uranium percentage variable.

Color: gray to olive-green to dark brown, somewhat shining.
Luster: submetallic to greasy or pitchy and dull.
Diaphaneity: opaque.
Crystallization: isometric; octahedrons, cubes, dodecahedrons; crystals rare.
Cleavage: not definite.
Fracture: conchoidal to uneven.
Tenacity: brittle.
Hardness: 5.5.
Specific gravity: 9—9.7; massive forms lower—from 6.4 up.

Occurrence: in granite rocks and in veins as a black massive mineral, often botryoidal in surface and of pitch-like appearance.

Tests: Infusible or slightly rounded on edges. When copper is present, gives green flame. Borax and salt of phosphorus beads are yellow in O.F., but green in R.F. Soluble in nitric and sulphuric acids. Put a sensitive photographic plate in a plate holder, or wrap it in black paper, and lay a cardboard over it. Place the powdered mineral or a good sized lump over the plate and leave it there from twelve hours to several days. If uranium is present in any considerable quantity, the plate when developed will be light-struck.

Colorado: Jefferson and Gilpin Counties, at various mines.

Economic: uranium salts for use in porcelain-painting, glass-coloring, etc. Uranium breaks down and yields radium.

BROGGERITE, CLEVEITE, NIVENITE are varieties of uraninite.

CARNOTITE: Mainly a vanadate of uranium and potassium, with other bases, $K_2O.2UO_3.V_2O_5+8H_2O$. A silicate of vanadium possibly related to Roscoelite is generally present. The average of several analyses gives: vanadium pentoxide 20.5; uranium trioxide 60.27; potassium oxide 6.63; water 6.5 per cent.

Color and streak: chrome-yellow.

Luster: dull.

Diaphaneity: opaque, in powdery mass.

Crystallization: very minute crystals and powder.

Cleavage: none shown.

Fracture: obscure.

Hardness: very soft.

Occurrence: loose, as yellow, crystalline powder in cavities and seams and disseminated through sandstones.

Tests: Gives tests for uranium and vanadium. Salt of phosphorus bead: O.F. amber hot, golden-yellow cold; R.F. green hot, fine green cold. Completely soluble in nitric acid with green solution, in hydrochloric acid with yellow solution, and in sulphuric acid with orange solution. A drop or two of concentrated hydrochloric acid turns the mineral a rich red-brown. Water added changes the color to green or causes it to fade completely.

Colorado: Montrose, San Miguel, Dolores, Garfield, Rio Blanco, Routt, and other western counties.

Economic: important ore of uranium and vanadium.

Analyses of many Colorado and Utah ores show that there is comparatively little pure carnotite mined. In almost all the ore called carnotite the percentage of vanadium is much too high to satisfy the formula given above. In many cases the vanadium oxide equals or exceeds the uranium oxide in amount.

TYUYAMUNITE: A calcium carnotite, $CaO.2UO_3.V_2O_5.4H_2O$. Occurs in small yellow crystals with other uranium-vanadium minerals in western Colorado.

GUMMITE is a reddish-yellow to orange, red and reddish-brown alteration product of pitchblende, of doubtful composition, but mainly a hydrous oxide of uranium, containing from 60 to 75 per cent of UO_3. Greasy luster; yellow streak; hardness of 2.5—3; specific gravity of 3.9—4.2.

Tests: Yields much water and gives bituminous odor. With salt of phosphorus in O.F. gives yellow bead, which becomes green in the reducing flame (uranium), leaving undissolved skeleton of silica.

THOROGUMMITE is a thorium-bearing gummite. Hardness 4—4.5; specific gravity 4.43—4.54.

PATRONITE: Vanadium sulphide VS_4, (or possibly an even higher sulphide); vanadium by the formula VS_4 would be 28.6 per cent. The average of four analyses by Hillebrand gives vanadium 25.48 per cent.

Color: dark green, resembling olivenite.

Crystallization: apparently amorphous.

Fracture: conchoidal to uneven.

Hardness: 3.5.

Streak: greenish-black.

Specific gravity: 2.65.

Occurrence: The mineral was first found in Peru, where it occurs in a vein following the bedding of Cretaceous shales. (*Eng. Min. Jour.*, Vol. 82, p. 385; *Am. Jour. Sci.*, Vol. 174 ~~147~~, p. 141.) It is reported from several localities in western Colorado, but the writer has not been able to verify the reports. A vanadium mineral from near Newmire, called by the finder "patronite," did not answer the description.

ROSCOELITE, VANADIUM MICA: A complex silicate of doubtful formula, but possibly $H_8K(Mg,Fe)(Al,V)_4(SiO_3)_{12}$; vanadium trioxide, V_2O_3, 20 to 28 per cent.

Color: various shades of brown and green, but olive-green is probably commonest in Colorado.

Luster: pearly when fresh, but often weakly pearly to earthy.

Diaphaneity: translucent to almost opaque.

Crystallization: minute scales, in groups, variously arranged—as fans, rosettes and stars, in which the scales are sometimes folded and crumpled.

Cleavage: perfect, basal.

Hardness: 1—1.5.

Streak: pale, earthy-greenish.

Specific gravity: 2.92—2.94.

Occurrence: in Magnolia district with quartz, calaverite and other vein minerals; in western Colorado in the La Plata sandstone as minute scales, scaly bunches, and irregular grains of olive-green to brownish-green color.

Tests: Fuses easily to black glass; in O.F. with salt of phosphorus a dark-yellow bead; in R.F. an emerald-green bead. Only slightly acted upon by acids.

Colorado localities: Magnolia district and other places in Boulder County, San Miguel County; also reported from Montrose and Dolores Counties, and other localities in western Colorado.

VANADINITE: A chloro-vanadate of lead, $3Pb_3(VO_4)_2.PbCl_2$ or $Pb_5Cl(VO_4)_3$; vanadium pentoxide, V_2O_5, 19.4 per cent, lead 73.0 per cent.

Color: deep red to bright red to orange to brown and yellow.

Luster: resinous on fracture.

Diaphaneity: translucent to opaque.

Crystallization: hexagonal-pyramidal. Crystals prismatic with sharp outlines; also in rounded forms and parallel groupings. Hollow crystals are common.

Cleavage: obscure or none.

Fracture: uneven to flat conchoidal.

Tenacity: brittle.

Hardness: 2.75—3.

Streak: white to pale yellow.

Specific gravity: 6.66—7.1.

Occurrence: crusts and bunches of globular crystals, and frequently sharp, well-defined crystals.

Associations: wulfenite, pyromorphite, descloizite.

Tests: On charcoal fuses easily to black mass, yielding yellow sublimate and metallic lead in reducing flame. Residue after lead is oxidized away gives, with salt of phosphorus in R.F., emerald-green, in O.F. light yellow. Decomposed by hydrochloric acid. Nitric acid causes deep red, then dissolves to yellow solution.

Economic: Ore of vanadium, which is used in steel manufacture. Salts of vanadium are used in dyeing silks, making vanadium bronze and vanadium ink.

Colorado: Montrose and San Miguel Counties.

UVANITE is a brownish-yellow hydrous uranium vanadate resembling carnotite in general appearance and mode of occurrence. It is found in the form of minute crystalline particles. The composition is $2UO_3,3V_2O_5.15H_2O$. It is insoluble in water, but readily soluble in ammonium carbonate. It occurs in commercial quantity in the vicinity of Temple Rock, Emery County, Utah, probably in the upper part of the Dolores formation.

ENDLICHITE has less vanadium and more arsenic than vanadinite.

HEWETTITE: A hydrous vanadate of calcium, $CaO.3V_2O_5.9H_2O$; V_2O_5 68.2 per cent, V_2O_4 1.2 per cent.

Color: deep red.

Luster: somewhat silky.

Crystallization: orthorhombic (?) in aggregates of microscopic needles.

Cleavage: not recorded.

Specific gravity: 2.5—2.6.

Tests: loses water on heating, changes color through shades of brown to bronze. Easily fusible to dark red liquid. Slightly soluble in water.

Occurs: Paradox Valley, Colo.

METAHEWETTITE: differs from hewettite in crystal habit, in the manner in which it loses water, and the color changes it passes through.

PINTADOITE is a hydrous calcium vanadate, $2CaO.V_2O_5.9H_2O$, in which the V_2O_5 forms 42.4 per cent. It occurs as a thin green efflorescence on the faces of cliffs protected from the weather. It is soluble in cold water and crystallizes from solution in the form of twinned lath-shaped crystals. In the natural occurrences crystal boundaries were not seen. It is probably of no commercial importance.

DESCLOIZITE is described elsewhere.

URANIUM MINERALS OF LESS IMPORTANCE

TORBERNITE, COPPER URANITE: A hydrous phosphate of uranium and copper, $Cu(UO_2)_2P_2O_8+8H_2O$; uranium trioxide, UO_3, 61.2 per cent.

Color: various shades of green.

Luster: pearly to subadamantine.

Diaphaneity: transparent to weakly translucent.

Crystallization: tetragonal; square tablets varying in thickness; sometimes in pyramids and micaceous aggregates.

Cleavage: one perfect.

Tenacity: brittle.

Hardness: 2—2.5.

Streak: paler than color.

Specific gravity: 3.4—3.6.

Occurrence: crystals and foliated masses.

Tests: Fuses easily to black mass, coloring flame green (copper). Borax bead is green in O.F., but red and opaque in R.F. Soluble in nitric acid.

Economic: possible source of uranium.

AUTUNITE, LIME URANITE, a hydrous phosphate of uranium and calcium, in form, hardness and occurrence resembling torbernite, but yellow in color. Specific gravity: 3.05—3.19. Gives same reactions as torbernite, except that for copper.

Colorado: Near Georgetown, Peabody lode; Chicago Creek.

URANOSPHAERITE, $Bi_2O_3.2UO_3.3H_2O$; uranium trioxide, UO_3, 52.7 per cent, bismuth trioxide, Bi_2O_3, 42.4 per cent. It is an orange-yellow to brick-red mineral of greasy to silky luster, having a hardness of 2.3, a specific gravity of 6.36, and occurring in minute, sharp-pointed crystals arranged in half-globular masses, sometimes showing rather smooth sublustrous surfaces, sometimes rough and drusy. *Tests*: When heated separates into mass of brown, needle-like crystals of silky luster.

URANOPHANE is a hydrous silicate of uranium and calcium, $CaO.2UO_3.2SiO_2+6H_2O$; uranium trioxide 76.0 per cent. It is a yellow mineral of vitreous to pearly luster, hardness of 2—3, specific gravity of 3.8—3.9, occurring in groups of radiating acicular prisms and fine fibrous masses, probably as an alteration of uraninite and gummite.

ZEUNERITE is an arsenate of copper and uranium, $CuO.2UO_3.As_2O_5.8H_2O$; uranium trioxide, UO_3, 56.0 per cent. It occurs in green, tabular crystals having a perfect cleavage, a pearly luster, an uneven fracture, a hardness of 2—2.5, a specific gravity of 3.2.

Tests for uranium: 1. Salt of phosphorus bead: in O.F. yellow while hot, yellowish green when cold; in R.F. fine green when cold. 2. Powdered mineral is dissolved in HCl, or fused with soda, then dissolved in HCl. Add ammonia until solution is nearly neutral. (If precipitate forms add acid slowly until it is dissolved.) Add powdered ammonium carbonate until no more precipitate is formed, let stand, filter, acidify with hydrochloric acid, boil, add ammonia in excess. Yellow precipitate indicates uranium. Filter and test precipitate with bead. Dissolve precipitate in little dilute sulphuric acid, add zinc. Blue solution turning green confirms other tests.

Tests for vanadium: 1. Borax bead: in O.F., yellow when hot, colorless when cold; in R.F. dirty green when hot, fine green when cold. 2. Salt of phosphorus bead; in O.F. yellow to amber when hot, paler when cold; in R.F., dirty green when hot, fine green when cold. 3. Fuse powdered mineral in 4 parts soda and 2 parts niter. Dissolve mass in hot water, filter, acidify with acetic acid, and add lead acetate; pale yellow precipitate fading to white. If molybdenum or chromium is suspected, dissolve the fused mass in water and add powdered ammonium chloride until it dissolves very slowly, and let stand. Faint yellowish precipitate indicates vanadium. Filter and wash precipitate with solution of ammonium chloride, heat slowly in porcelain crucible. Red residue is vanadium pentoxide.

VANADIUM AND URANIUM ORES OF WESTERN COLORADO

Vanadium occurs in several ores of quite distinct appearance:

1. A rather pale olive sandstone, graduating into a very dark green rock speckled with carnotite. The color is due to the vanadium-bearing mineral forming a cementing material between the

grains. This mineral is closely related to roscoelite, but the percentages of Al_2O_3 and V_2O_5 are reversed.

2. Carnotite has been described.

3. A dark brownish sandstone in which the bonding material is a mineral containing vanadium, and a little uranium. The rock strongly resembles an ordinary iron charged sandstone, but it contains very little iron. So far as the writer is aware no name has been given to this mineral.

4. A very dark green or greenish black sandstone, the broken surface of which has a dull waxy or oily luster. The cementing material is a vanadium mineral carrying little or no uranium, locally called Kentsmithite, but it is probably almost identical with the darker part of the ore described under number one. A sandstone of similar appearance carries a little vanadium.

5. Calciovolborthite or possibly volborthite has been reported from two or more localities.

6. The dark pitchy or coaly looking material carrying manganese and much carbon does not appear to be a separate mineral. It is sometimes well charged with carnotite and possibly one of the other vanadium-bearing minerals.

Tests: The tests for carnotite and roscoelite are described under those minerals.

The brown sandstone: When treated with acids the brown mineral is readily dissolved leaving the white sand grains. With hydrochloric acid the solution is first red, then brownish yellow, cooling to yellowish green. With nitric acid the solution is dark red, fading rapidly to almost colorless. It reacts for both uranium and vanadium. If the acid solution is made almost neutral with ammonia and hydrochloroplatinic acid is added a yellow precipitate shows the presence of potassium. Aluminum is also present.

The dark green sandstone: The vanadium mineral of this ore is not so readily soluble as that of the brown sandstone. But enough can be brought into solution with strong hydrochloric acid to yield tests for vanadium. The reactions are more positive if the mineral is fused with sodium carbonate. In most respects it resembles roscoelite. It contains little or no uranium, but gives a good reaction for potassium, and aluminum, and occasionally carries an appreciable amount of manganese.

Uranium ore: Only the carnotite appears to carry uranium in commercial amount.

URANIUM MINERALS NOT DESCRIBED: Uranothalite, Uranopilite, Johannite, Uraconite, Uranospinite, Uranocircite, Walpurgite.

VANADIUM MINERALS NOT DESCRIBED: Vanadium-bearing minerals are very numerous, but many of them are very rare. A few seem to be worthy of mention. They are: Vanadic ochre, Ardennite.

COPPER AND COPPER MINERALS

USES OF COPPER: The most important use of metallic copper is as a conductor of electricity. Of the common metals only silver is a better electrical conductor than copper. Aluminum is also used as a conductor. In conductivity the three rank as follows: silver 100, copper 96, aluminum 63. Copper is used in many commercial alloys, and the quantity consumed in this way is very large. Brass is an alloy of copper and zinc. The use for which it is intended determines the proportion of the two metals. The commonest proportion is about two of copper to one of zinc, but there are scores of brasses in use. Bronze, gun-metal, bell-metal, are alloys of copper, tin and generally zinc. The tone of the bell is determined largely by the ratio in which the two metals are used. German silver is an alloy of copper, zinc and nickel. Statuary bronze contains copper, tin and zinc. Phosphor-bronze is a bronze purified by fluxing with phosphorus. Many alloys of aluminum and copper are in commercial use. That containing about 10 per cent of aluminum is known as aluminum bronze. An alloy of copper, aluminum and tungsten is used for propeller blades. Copper is extensively used in the arts and trades: covering ships' bottoms, roofing, domestic utensils, plumbing, copper-plate engraving. The salts of copper are also extensively used. The sulphate is used in electrotyping, copper-plating, calico-printing, sanitary engineering, galvanic batteries, etc. Cupric oxide is used in oil-refining and in organic chemistry. Several salts of copper are used as pigments, especially green and blue. In many countries metallic copper is the principal metal used in coins of the lower denomination.

MINERALS IMPORTANT AS ORES OF COPPER

CHALCOCITE, COPPER GLANCE: Cu_2S; copper 79.8 per cent, sulphur 20.2 per cent.

Color: blackish to lead-gray.

Luster: metallic in the crystal, dull in soft variety.

Crystallization: orthorhombic; crystals commonly hexagonal in outline.

Cleavage: poor.

Fracture: conchoidal. Brittle.

Hardness: 2.5—3 for crystals; also soft, earthy.

Streak: blackish to lead-gray.

Specific gravity: 5.5—5.8.

Occurrence: massive, granular to compact, also soft powdery form; often secondary from alteration of other copper minerals.

Associations: other copper ores, pyrite, quartz and calcite.

Tests: Open tube, sulphur fumes. On coal, melts to a globule which sputters. The fine powder roasted O.F., then heated R.F., gives metallic copper.

COPPER: Metallic copper, Cu.

Color: Copper-red.

Luster: metallic on fresh surfaces, but old surfaces become dull.

Crystallization: isometric; cubes, tetrahedrons, and other forms.

Cleavage: none.

Fracture: rough, hackly.

Hardness: 2.5—3.

Streak: metallic-shining.

Specific gravity: 8.8—8.9.

Occurs: strings, sheets, arborescent masses, lumps and scattered grains in sandstone, conglomerate, amygdaloidal rocks, etc.

Tests: Fuses easily; cooling, becomes covered with dark oxide; nitric dissolves it, and addition of ammonia gives deep blue.

Remarks: Probably always derived from copper minerals by processes of alteration.

ENARGITE: A sulph-arsenate of copper, Cu_3AsS_4 or $3Cu_2S.As_2S_5$ (often contains antimony); copper 48.3 per cent, sulphur 32.6 per cent, arsenic 19.1 per cent.

Color: grayish-black to iron-black.

Luster: metallic to submetallic.

Crystallization: orthorhombic; crystals rare.

Cleavage: one perfect and two distinct.

Fracture: uneven and ragged.

Hardness: 3.

Streak: grayish-black to iron-black.

Specific gravity: 4.43—4.45.

Occurs: as an ore, massive, granular, showing good cleavage faces on broken surfaces.

Associations: various sulphide ores of copper, pyrite and gold ores.

Tests: Closed tube, decrepitates and deposits sulphur, and at higher temperatures fuses and deposits sulphide of arsenic. On coal, fuses and gives faint coating of oxides of arsenic, antimony and zinc. Soluble in aqua regia.

CHALCOPYRITE, COPPER PYRITES, YELLOW COPPER ORE: $CuFeS_2$ or $Cu_2S.Fe_2S_8$; copper 34.5 per cent, iron 30.5 per cent, sulphur 35 per cent.

Color: brassy-yellow, often tarnished and iridescent.

Luster: metallic.

Crystallization: tetragonal; crystals commonly tetrahedral in appearance.

Cleavage: poor.

Fracture: uneven. Brittle.

Hardness: 3.5—4.

Streak: greenish-black.

Specific gravity: 4.1—4.3.

Occurs: compact massive, in sedimentary, igneous and metamorphic rocks, in veins and contact deposits.

Associations: pyrite, bornite, tetrahedrite, pyrrhotite, siderite, vein quartz.

Tests: Closed tube, decrepitates and deposits sulphur on the tube. Open tube, sulphur fumes. On coal, fuses to magnetic globule. Fluxes, reacts for iron and copper.

Differences: softer and deeper yellow than pyrite, brittle while gold is not, soluble in nitric acid while gold is not.

PYRITE: Cupriferous pyrite is an important ore of copper in Arizona, Tennessee and elsewhere. The percentage of copper ranges from a fraction of 1 per cent up to that of chalcopyrite, 34.5.

PYRRHOTITE is frequently copper-bearing, but is rarely important as an ore of copper.

BORNITE, PURPLE COPPER ORE, VARIEGATED COPPER ORE: Massive forms vary, but crystals are Cu_3FeS_3; copper 55.5 per cent, iron 16.4 per cent, sulphur 28.1 per cent.

Color: copper-red to pinchbeck-brown on new surfaces, but quickly becomes iridescent from tarnish.

Luster: metallic.

Crystallization: isometric; cubes often with curved faces.

Cleavage: seldom seen.

Fracture: small conchoidal, uneven. Brittle.

Hardness: 3.

Streak: pale grayish-black.

Specific gravity: 4.9—5.4.

Occurs: massive, granular or compact.

Association: other copper ores, especially the sulphides, arsenides, etc.

Tests: Closed tube, faint sublimate of sulphur. Open tube, sulphur fumes. Coal, R.F. brittle metallic globule, magnetic. Coal and soda, metallic globule. Other copper and iron reactions.

TETRAHEDRITE, GRAY COPPER ORE: A sulph-antimonite of copper. Composition varies, but is generally $Cu_8Sb_2S_7$ or $4Cu_2S.Sb_2S_3$; sulphur 23 per cent, antimony 24.8 per cent, copper 52.9 per cent.

Color: between flint-gray and iron-black.

Luster: metallic, often splendent.

Crystallization: isometric; tetrahedrons.

Cleavage: none.

Fracture: subconchoidal, uneven. Brittle.

Hardness: 3—4.

Streak: between flint-gray and iron-black, but sometimes brown to red.

Specific gravity: 4.4—5.1.

Occurrence: massive, granular, coarse or fine, compact.

Associations: chalcopyrite, pyrite, sphalerite, galena, siderite.

Tests: Differs with composition. Closed tube usually gives red sublimate of antimony. Open tube, fumes of sulphur, fuses, and gives white sublimate of antimony oxide. Gives with roasted mineral reactions for copper and usually iron.

Colorado localities: in many mines in San Juan, Clear Creek, Gunnison and Boulder Counties. Much that is called tetrahedrite is tennantite.

TENNANTITE, sulpharsenite of copper, $Cu_8As_2S_7$ or $4Cu_2S.As_2S_3$; copper 57.5 per cent, arsenic 17 per cent. Often contains antimony and grades into tetrahedrite. It is almost indistinguishable from tetrahedrite, except by analysis. The tests show arsenic predominating, instead of antimony as in tetrahedrite. *Colorado localities*: Much of the ore called tetrahedrite (gray copper) in Colorado is tennantite.

MALACHITE: $CuCO_3.Cu(OH)_2$ or $2CuO.CO_2.H_2O$; carbon dioxide 20 per cent, copper 57.4 per cent, oxygen 14.6 per cent, water 8.2 per cent.

Color: bright green.

Luster: adamantine, inclining to vitreous, sometimes silky; often dull earthy.

Diaphaneity: sometimes translucent, but usually opaque.

Crystallization: monoclinic; crystals rarely distinct, usually slender, needle-like and tufted.

Cleavage: seldom observable, though basal cleavage is prominent in good pure mineral.

Fracture: subconchoidal.

Hardness: 3.5—4.

Streak: paler green.

Specific gravity: 3.9—4.03.

Occurrence: commonly massive, or incrusting, with botryoidal surface and divergent structure. Often delicately compact fibrous, and banded in structure and color. Frequently granular or earthy. Found in upper, weathered parts of copper deposits.

Associations: azurite, chrysocolla, melaconite and tenorite, cuprite.

Tests: Closed tube, blackens and loses water. Coal, fuses at 2, coloring the flame emerald-green, and is reduced to metallic copper. Soluble with effervescence in the acids, giving off carbon dioxide.

NOTE.—Finely colored malachite is cut for gems and ornamental stones.

AZURITE: $2CuCO_3.Cu(OH)_2$, or $3CuO.2CO_2.H_2O$; copper 55 per cent.

Color: azure-blue to Berlin-blue.

Luster: vitreous, almost adamantine.

Crystallization: monoclinic. Crystals highly modified. Tabular forms commonest.

Cleavage: good.
Fracture: conchoidal. Brittle.
Hardness: 3.5—4.
Streak: blue, lighter than the mineral.
Specific gravity: 3.77—3.83.
Occurrence: massive, often columnar structure; also dull and earthy. Mainly in upper weathered portions of deposits.
Association: malachite, tenorite, chrysocolla, native copper, and other ores of the altered zone.
Tests: same as for malachite.

NOTE.—Choice pieces of fine color and concentric structure are cut for gems and ornamental stones.

CUPRITE, RED COPPER OXIDE: Cuprous oxide, Cu_2O; copper 88.8 per cent.
Color: red of various shades, sometimes almost black, and occasionally crimson.
Luster: submetallic to earthy.
Crystallization: isometric; octahedrons, cubes and dodecahedrons.
Cleavage: poor.
Fracture: conchoidal uneven.
Hardness: 3.5—4.
Streak: shades of brownish-red.
Specific gravity: 5.65—6.15.
Occurrence: massive, granular, sometimes earthy.
Associations: native copper, azurite and malachite, chalcocite, limonite, etc.
Tests: Closed tube, unaltered; in forceps, fuses, coloring flame green. On coal, blackens and fuses to metallic copper. Soluble in concentrated hydrochloric acid. A strong solution cooled and diluted with cool water gives a heavy white precipitate of subchloride of copper.
Differences: softer than hematite, harder than cinnabar and ruby silver.

CHALCOTRICHITE is a variety of cuprite occurring in hair-like crystals.

TENORITE (in lustrous scales), MELACONITE (earthy, black, massive): Cupric oxide, CuO; copper 79.8 per cent.
Color: steel-gray to iron-gray when in scales; earthy-black or grayish-black, soiling the fingers.

Luster: metallic when hard; dull and earthy when soft.
Diaphaneity: opaque.
Crystallization: rarely shows crystal form; thin shining flakes and flexible scales; earthy, massive and powdery.
Cleavage: one good.
Fracture: conchoidal to uneven.
Hardness: 3—4; mostly in soft, powdery masses.
Streak: black.
Specific gravity: 5.8.
Tests: B.B. in oxidizing flame infusible. For other reactions see cuprite. Soluble in nitric and hydrochloric acids.
Occurs: mainly in highly oxidized zones of copper ores, from alteration of other copper minerals.

LAMPADITE is a wad containing 4 to 18 per cent copper, and sometimes graduating into melaconite.

BROCHANTITE, a basic sulphate of copper, $4CuO.SO_3.3H_2O$; copper 56.1 per cent; is a transparent to translucent emerald to very dark-green mineral of vitreous to pearly luster, perfect cleavage, uneven fracture, a hardness of 3.5—4, and a specific gravity of 3.9. It occurs in stout orthorhombic crystals, often long and slender; also in crusts and druses, and rounded granular masses. It is formed as a result of the alteration of sulphide ores of copper near the surface, and is very commonly intergrown with malachite. The sulphide breaks up, forming a sulphate solution, from which the brochantite is deposited by evaporation. It has been reported from several Colorado localities, particularly in the Monarch district in Chaffee County, and it is very probable that much that is called malachite is, in reality, a mixture of malachite and brochantite.

COVELLITE: Cupric sulphide, CuS; copper 66.4 per cent.
Color: indigo-blue or darker, often iridescent.
Luster: submetallic to resinous, to dull when massive.
Diaphaneity: opaque.
Crystallization: hexagonal, but rarely in crystals; commonly massive or spheroidal, flaky or platy, and granular.
Cleavage: one perfect.
Fracture: irregular. Thin plates are flexible.
Hardness: 1.5—2.
Streak: lead-gray to black.
Specific gravity: 4.59.

Tests: In closed tube gives deposit of sulphur; in open tube, sulphur fumes. B.B. on charcoal burns with blue flame and fuses to globule, which reacts like chalcocite.

Colorado: Cashin and other mines in Montrose County.

CHRYSOCOLLA, COPPER SILICATE: Varies through impurities, such as silica, alumina, copper oxides, etc. Pure mineral is $CuSiO_3.2H_2O$; copper 36 per cent, silica 34.3 per cent, water 20.5 per cent, oxygen 9 per cent.

Color: mountain-green, bluish-green and almost sky-blue; brown, etc.

Luster: vitreous, shining, earthy.

Diaphaneity: translucent to opaque.

Crystallization: cryptocrystalline, often opal-like or enamel-like, and earthy.

Cleavage: none.

Fracture: conchoidal.

Tenacity: rather sectile; translucent varieties are brittle.

Hardness: 2—4.

Specific gravity: 2—2.2.

Occurrence: incrusting or filling seams. Sometimes botryoidal, mainly in the upper part of veins.

Associations: other copper ores, especially the carbonates.

Tests: Closed tube, blackens and loses water. Coal, decrepitates, colors flame green, but does not fuse. Fluxes give copper reactions. With soda gives metallic copper. Soluble in acids without gelatinization.

NOTE.—Choice pieces of chrysocolla are cut and polished for ornamental purposes.

COPPER-PITCH ORE is a name applied to a dark-brown to black substance, having a dull to resinous and sometimes glassy luster, and a dark-brown streak. It breaks with a smooth, somewhat conchoidal fracture, and has a hardness of about 4. It shows no cleavage or other evidence of crystallization. It occurs with azurite, malachite, chrysocolla, and other products of alteration of vein minerals. Analysis shows that it contains copper, manganese, iron, zinc, and other metals in the oxide form. A similar material, containing mainly black oxide of copper and limonite, occurs in the oxidized zone of a number of copper deposits.

MELANOCHALCITE is very similar to copper-pitch in general appearance and mode of occurrence, but is shown by analyses to be a hydrous silico-carbonate of copper.

COPPER MINERALS RARELY IMPORTANT AS ORES OF COPPER

RICKARDITE is a copper telluride, Cu_4Te_3 or $Cu_2Te.2CuTe$; copper 40.74 per cent. *Color*: deep purple, resembling tarnished bornite. *Luster*: metallic. *Diaphaneity*: opaque. *Crystallization*: massive. *Fracture*: irregular to rather smooth, brittle. *Hardness*: 3.5. *Specific gravity*: 7.54. *Tests*: Fuses very easily to brittle globule, coloring flame pale azure tinged with green, and forming white coating of TeO_2; dissolves in nitric acid; with strong sulphuric acid gives reddish-violet solution.

Colorado localities: Vulcan.

ATACAMITE: Oxychloride of copper, $Cu_2Cl(OH)_3$; copper 59.45 per cent.

Color: green of almost all shades, to greenish-black when oxidized.

Luster: adamantine to vitreous, and when fibrous, silky.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; slender, prismatic, striated crystals; more commonly in crystal aggregates and fibrous and granular masses. and as a sand. Sometimes the crystals are bladed parallel to the cleavage.

Cleavage: one highly perfect.

Fracture: conchoidal. Brittle.

Hardness: 3—3.5.

Streak: apple-green.

Specific gravity: 3.75.

Alteration: frequently to malachite, occasionally to chrysocolla.

Tests: In closed tube yields much water and a grayish sublimate. B.B. on charcoal fuses to a metallic, copper-red button, coloring the flame a persistent blue, due to the chlorine present. Soluble in acids to a green solution.

Economic: occasionally an ore of copper.

Colorado: Kendall Mountain.

AURICHALCITE is a basic carbonate of copper and zinc, $2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$; varying in color from pale green to sky-blue, and having a pale-green to bluish streak. It has a hardness of 2, a specific gravity of 3.54—3.64, a pearly luster, and is translucent. The percentage of copper varies widely, but zinc commonly exceeds the copper in amount.

DIOPTASE is a hydrous silicate of copper, $CuO.SiO_2.H_2O$; copper 40.0 per cent. It is a transparent to translucent, vitreous mineral of emerald-green color, perfect cleavage, conchoidal to uneven fracture. *Hardness*: 5. *Specific gravity*: 3.28—3.35. *Occurs*: in prismatic crystals, crystal aggregates, and massive forms lining cavities and forming crusts. *Tests*: In closed tube blackens and yields water. B.B. flies to pieces, colors flame copper-green. With soda on charcoal yields metallic copper. Yields a jelly with hydrochloric acid.

LIBETHENITE, a hydrous phosphate of copper, $4CuO.P_2O_5.H_2O$, is a translucent, olive-green to very dark-green mineral of resinous to subvitreous luster, poor cleavage, uneven fracture, a hardness of 4, specific gravity of 3.6—3.8. It occurs with malachite in and about bodies of chalcopyrite. It is not known as an important ore.

OLIVENITE, olive-green copper ore, is a hydrous arsenate of copper, $4CuO.As_2O_5.H_2O$; copper 51.1 per cent; arsenic pentoxide, As_2O_5, 40.7 per cent. *Color*: various shades of green, brown, yellow and grayish-white. *Luster*: adamantine to vitreous and earthy. *Translucent to opaque. Crystallization*: orthorhombic prisms and needles, fibrous masses of globular and kidney form. *Cleavage*: poor. *Fracture*: conchoidal to uneven, brittle. *Hardness*: 3. *Specific gravity*: 4.1—4.4. *Streak*: olive-green to brown. *Tests*: B.B. fuses easily, giving bluish-green flame (arsenic and copper); on charcoal, yields arsenic fumes and flames up; forms a globule which with soda gives metallic copper. Soluble in nitric acid.

WOOD COPPER is a finely fibrous variety of olivenite, often having a velvety surface. Specific gravity 3.9.

CHALCANTHITE, Copper Sulphate, Blue Vitriol: Hydrous sulphate of copper, $CuSO_4.5H_2O$; copper 25.3 per cent. It is a blue, translucent to transparent mineral of vitreous luster, imperfect cleavage, conchoidal fracture, a specific gravity of 2.1—2.3, and a hardness of 2.5. It occurs in crusts of crystals, stalactites, botryoidal crusts and masses, resulting from the evaporation of mine waters charged with copper sulphate from the disintegration of chalcopyrite and possibly other sulphide ores of copper. It sometimes fills seams and small fissures, and occasionally forms large masses.

COPPER MINERALS NOT DESCRIBED: Algodonite, Domeykite, Whitneyite, Chalcostibite, Emplectite, Clinoclasite, Euchroite, Chalcophyllite, Gerhardite, Spangolite, Chalcomenite.

LEAD AND LEAD MINERALS

USES: Metallic lead in sheets and pipes is extensively used in plumbing, roofing, and in the acid industry. It is also used for weights, ballast in small vessels, shot, bullets. Alloys of lead are numerous and very useful. Type metal is an alloy of lead and antimony; solder is lead and tin; pewter is lead, tin, copper, and antimony or bismuth. Low-fusion alloys containing lead, bismuth and tin are used for fire plugs in automatic fire devices. Alloys of lead are used as anti-friction metals for the bearings of heavy machinery. Organ-pipe metal is an alloy of lead.

Salts of lead find many uses in the trades and industries. Litharge, PbO, and minium, Pb_3O_4, are used in glass-making. Litharge is used as a glaze for pottery, and as a collecting agent in assaying. Dutch, French, English white lead is a hydrate-carbonate of lead, $2PbCO_3.Pb(OH)_2$, extensively used as a pigment. Sublimed white lead is a mixture of lead sulphate, lead oxide, and zinc oxide. The composition is usually about $PbSO_4$ 75 per cent, PbO 20 per cent, ZnO 5 per cent. It is an excellent pigment. Sublimed blue lead consists of lead sulphate 50—53 per cent, lead oxide 38—41 per cent, with small amounts of lead sulphide, lead sulphite, and zinc oxide. Minium is used as a red pigment. Various mixtures of "white lead" and zinc oxide are used as white pigments. Lead chromates are used as yellow and red pigments. Lead acetate, sugar of lead, is extensively used in the arts.

LEAD MINERALS IMPORTANT AS ORES

GALENA, Galenite, Lead Sulphide, Lead Glance: PbS; lead 86.6 per cent, sulphur 13.4 per cent.

Color and streak: pure lead-gray.

Luster: metallic.

Crystallization: isometric; cubes and cubo-octahedrons.

Cleavage: cubical, perfect.

Fracture: flat, subconchoidal or even.

Hardness: 2.5—2.75.

Specific gravity: 7.4—7.6.

Association: other lead minerals, pyrite, zinc blende, siderite.

Occurs: massive, cleavable, coarse or fine granular to powdery fineness. Broken surfaces of massive ore show cleavage faces.

Alteration: Cerussite and anglesite form in the upper weathered portions of deposits.

Tests: Open tube gives fumes of sulphur; on coal gives sulphur and fuses to globule of metallic lead, coating the coal yellow near the assay, but white farther away. Soluble in strong nitric acid, giving white, powdery precipitate.

Remarks: The very fine granular variety is called steel galena. The finer-grained varieties may contain enough silver to make them valuable silver ores.

CERUSSITE, WHITE LEAD ORE, LEAD CARBONATE: Carbonate of lead, $PbCO_3$; lead 77.5 per cent.

Color: white, gray, yellowish, gray-black, sometimes tinged blue or green.

Luster: adamantine, inclining to vitreous, resinous or pearly; sometimes submetallic.

Diaphaneity: crystals, transparent to translucent.

Crystallization: orthorhombic; simple tabular, prismatic and pyramidal crystals. Twinned and grouped, often radiating.

Cleavage: one distinct.

Fracture: conchoidal. Very brittle.

Hardness: 3—3.5.

Streak: white.

Specific gravity: 6.46—6.57.

Occurs: granular massive and compact; earthy and rarely fibrous, sometimes stalactitic, frequently in bunches and open masses of slender prismatic crystals.

Tests: Closed tube, decrepitates, loses carbon dioxide, turns yellow, and at higher temperature dark red, but yellow again on cooling. On coal, fuses easily, and in R.F. gives metallic lead. Soluble with effervescence in diluted nitric acid.

Remarks: It is formed from the alteration of galena.

ANGLESITE, LEAD SULPHATE: Sulphate of lead, $PbSO_4$; lead 68.3 per cent.

Color: colorless, white, tinged yellow, gray, and sometimes blue.

Luster: highly adamantine in some specimens, inclining to resinous and vitreous in others.

Diaphaneity: transparent to opaque.

Crystallization: orthorhombic; crystals usually prismatic, sometimes tabular.

Cleavage: in one direction is distinct.

Fracture: conchoidal. Very brittle.

Hardness: 2.75—3.

Streak: white.

Specific gravity: 6.3—6.39.

Occurs: massive granular to compact stalactitic, nodular, often encrusting galena from which it is formed. Found in upper parts of lead deposits.

Tests: Decrepitates, fuses easily; on coal O.F. fuses to a clear pearl, becoming milk-white on cooling; with soda R.F. gives metallic lead and the soda is absorbed into the coal. On coal alone R.F effervesces and is reduced to metallic lead. Difficulty soluble in nitric acid. The best solvent is ammonium acetate.

Differences: Cerussite effervesces in the acids; it is heavier than barite or celestite, and gives different flame coloration. Yields lead in R.F. on coal.

PYROMORPHITE: Mainly lead phosphate, $3Pb_3(PO_4)_2.PbCl_2$; lead 76.28 per cent.

Color: green, yellow, orange, brown, gray, white.

Luster: resinous.

Diaphaneity: weakly translucent to opaque, occasionally approaching transparency.

Crystallization: hexagonal; short, stout hexagonal prisms, often branching and tapering, sometimes hollow.

Cleavage: poor.

Fracture: subconchoidal to uneven. Brittle.

Hardness: 3.5—4.

Streak: white to pale yellow.

Specific gravity: 6.5—7.1.

Occurrence: commonly in veins as incrustations, showing poorly developed crystals, or interlaced fibers and slender crystals. Also botryoidal reniform and granular masses.

Tests: On coal, fuses readily, coating the coal yellow near the assay, white farther away. Globule cools to crystal form. With soda, reduces to lead; with salt of phosphorus saturated with copper oxide, gives azure-blue flame (chlorine). Soluble in nitric acid.

Remarks: Probably secondary from galena. Rarely occurs in large quantity.

LEAD MINERALS LESS IMPORTANT AS ORES

AIKINITE, NEEDLE ORE: Sulphobismuthite of lead and copper, $3(Pb,Cu_2)S.Bi_2S_3$—sometimes $PbCuBiS_3$; lead 36.0 per cent, copper 11.0 per cent, bismuth 36.2 per cent, sulphur 16.8 per cent.

Color: blackish lead-gray, with pale copper-red tarnish.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: orthorhombic; acicular, striated.

Fracture: uneven.

Hardness: 2—2.5.

Specific gravity: 6.1—6.8.

Tests: Open tube, yields sulphur fumes, and white sublimate which fuses into clear drops. With bismuth flux (2 parts sulphur, 1 part potassium iodide, 1 part acid potassium sulphate) on gypsum plate gives yellow (lead), chocolate and red (bismuth), coatings, and green flame (copper). Soluble in nitric acid with separation of lead sulphate and sulphur.

Economic: Reported as ore of bismuth and lead from mines in La Plata Mountains.

Remarks: Mistaken for cosalite and bournonite. Darker color than bournonite, and less lustrous. Cosalite contains little or no copper.

Colorado localities: Reported in fair quantities in La Plata Mountains.

COSALITE: A sulphide of lead and bismuth, $2PbS.Bi_2S_3$; lead 41.8 per cent, bismuth 42.0 per cent, sulphur 16.2 per cent. Silver and copper may be present, replacing lead.

Color: lead-gray to steel-gray.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: orthorhombic; crystals rare.

Fracture: uneven.

Tenacity: brittle.

Hardness: 2.5—3.

Streak: black.

Specific gravity: 6.39—6.75.

Occurs: usually massive and indistinctly crystalline; fibrous to coarse radiating.

Tests: Same as for aikinite, except copper reactions.

Economic: Reported as ore of lead and bismuth in La Plata quadrangle.

Remarks: Some of the ore from La Plata Mountains, called cosalite, is clearly aikinite.

Colorado localities: La Plata Mountains.

MIMETITE: A chlorarsenate of lead, $(PbCl)Pb_4As_3O_{12}$ or $3Pb_3As_2O_8.PbCl_2$; lead 69.5 per cent. Phosphorus may replace part of the arsenic, and calcium a part of the lead.

Color: pale yellow to brown; orange and white. Occasionally colorless.

Luster: resinous.

Diaphaneity: translucent to subtransparent.

Crystallization: hexagonal; prisms and pyramids like those of pyromorphite and vanadinite.

Cleavage: one poor.

Fracture: uneven.

Tenacity: brittle.

Hardness: 3.5.

Streak: white to whitish.

Specific gravity: 7—7.25.

Occurs: crusts of crystals and rounded or globular aggregates; also needle-like groups and coatings.

Associations: other lead minerals; frequently mistaken for pyromorphite and vanadinite.

Tests: B.B. fuses very easily, giving in reducing flame odor of arsenic and yielding metallic lead. Coats coal with lead chloride and later arsenic trioxide and lead oxide. Soluble in nitric acid. Reacts for chlorine, as does pyromorphite.

Economic: rarely in commercial quantities.

Colorado localities: Leadville.

HINSDALITE, a hydrous sulphate and phosphate of lead and aluminum, with a little strontium replacing lead, $2PbO.3Al_2O_3.2SO_3.P_2O_5.6H_2O$; lead 29.5 per cent.

Crystallization: hexagonal; rhombohedrons resembling cubes, and in coarsely crystalline granular masses.

Cleavage: basal, perfect.

Hardness: 4.5.

Specific gravity: 3.65.

Luster: vitreous to greasy.

Color: colorless to greenish-gray.

Streak: colorless.

Diaphaneity: translucent to transparent when pure.

Associations: barite, pyrite, galena, tetrahedrite and rhodochrosite.

It occurs as an ore in the Golden Fleece mine near Lake City, Colorado.

LEAD MINERALS RARELY IMPORTANT AS ORES

ALTAITE, lead telluride, PbTe; lead 62.3 per cent; is a tin-white sectile mineral of metallic luster, tarnishing to bronze yellow. It is usually massive, but sometimes forms cubes. B.B. on coal colors flame bluish, fuses to globule, coating coal near assay with lustrous metallic ring of lead telluride bordered by brownish-yellow. Volatilizes, leaving only trace of silver. In open tube fuses, gives fumes of tellurium dioxide, forming white sublimate which fuses into colorless drops. Occurs in several Boulder County mines.

CLAUSTHALITE, lead selenide, PbSe; lead 72.4 per cent; is a bluish-gray, galena-like mineral of metallic luster, cubic cleavage, granular fracture, hardness 2.5—3, gravity 7.6—8.8. B.B. partially fuses, giving selenium odor (decayed horseradish), and coating of gray bordered by red (selenium), and later yellow (lead oxide); when pure, entirely volatile; with soda gives globule of lead. In closed tube gives selenium fumes and red sublimate.

JAMESONITE is mainly a sulphantimonite of lead, $4PbS.FeS.3Sb_2S_3$; lead 40.32 per cent, antimony 35.10 per cent; of gray color and metallic luster, usually occurring in needle-like and fibrous crystals, but occasionally fibrous massive and compact massive. Cleavage, one good and two fair; hardness 2—3; gravity 5.5—6. B.B. fuses very easily and volatilizes almost completely, coating the coal dark yellow bordered by white. With hot hydrochloric acid yields hydrogen sulphide, and lead chloride on cooling; in open tube, sulphur fumes and white deposit of antimony trisulphide.

BOURNONITE: Sulphantimonite of lead and copper, $3(Pb,Cu_2)S.Sb_2S_3$; lead 42.5 per cent, copper 13.0 per cent, antimony 24.7 per cent, sulphur 19.8 per cent.

Color: steel-gray.

Luster: brilliant, metallic.

Diaphaneity: opaque.

Crystallization: orthorhombic; short prismatic and tubular crystals, often having striated faces.

Cleavage: one perfect and two fair.

Fracture: subconchoidal to uneven.

Tenacity: brittle.

Hardness: 2.5—3.

Streak: steel-gray.

Specific gravity: 5.7—5.9.

Occurs: in crystals, and massive, granular, compact.

Associations: many other complex minerals carrying lead, silver, antimony, bismuth.

Tests: B.B. on coal fuses easily, giving white coating, and later coating of yellow lead oxide; residue of assay reduced with soda yields copper, which colors flame green, or, if moistened with hydrochloric acid, azure-blue. Soluble in nitric acid, forming blue solution, and leaving residue of sulphur and white powder containing antimony and lead.

Economic: an unimportant ore of lead.

Remarks: Alters to cerussite, azurite, malachite.

Colorado localities: San Juan, particularly Silverton area.

ZINKENITE is a sulphantimonite of lead, $PbS.Sb_2S_3$; antimony 41.8 per cent, lead 35.9. It is an opaque, steel-gray mineral having a metallic luster, a steel-gray streak, a poor cleavage, a rather even fracture, a hardness of 3—3.5, a specific gravity of 5.3—5.35. It occurs in poorly defined orthorhombic crystals, and in columnar and fibrous masses and granular forms. *Tests*: B.B. flies to pieces, fuses very easily, and on coal is almost entirely volatilized, forming a yellow coating bordered with white. With soda in reducing flame yields metallic lead.

PHOSGENITE, a chlorocarbonate of lead, $PbCO_3.PbCl_2$; lead 77.8 per cent. Tetragonal, tabular and prismatic; cleavage, three distinct; sectile; hardness 3.0; specific gravity 6; luster adamantine; colorless, white, gray, yellow; streak white; transparent to translucent; B.B. melts easily to yellow globule, which cools white and crystalline; on coal R.F. metallic lead and white coating of lead chloride; effervesces in dilute nitric acid. Alters to cerussite.

MINIUM, an oxide of lead, Pb_3O_4; lead 90.6 per cent; is a vivid-red to yellowish-red, powdery or loosely compact mineral, having a specific gravity of 4.6, hardness of 2—3, a dull to greasy luster, and an orange-yellow streak. Gives the usual lead reactions and a lead globule. The pigment, red lead, is of the same composition.

DESCLOIZITE, $(Pb,Zn)(PbOH).VO_4$; lead 51.4 per cent, zinc 15.8 per cent, vanadium 12.7 per cent. Occurs as small prismatic or pyramidal, orthorhombic crystals, usually having striated faces; also massive, fibrous, radiated with mammillary surface. *Cleavage*: none. *Fracture*: smooth to uneven, brittle. *Hardness*: 3.5. *Specific gravity*: 5.9—6.2. *Luster*: greasy. *Color*: purplish-red, brown, black. *Streak*: orange to brown and yellowish-gray. *Diaphaneity*: transparent to subtranslucent. *Tests*: B.B. on coal, fuses to black mass inclosing globule of lead; with borax and salt of phosphorus in R.F. forms green glass. Dissolves in cold dilute nitric acid.

CUPRODESCLOIZITE: Tritochorite, Ramirite: A copper-bearing Descloizite, $(PbCu)_2(OH)VO_4$. Occurs in crusts having radiated structure. Reported from western Colorado.

LINARITE, a sulphate of lead and copper, $PbO.CuO.SO_3.H_2O$; lead 51.7 per cent, copper 15.78 per cent; is a deep azure-blue mineral occurring in elongated and tabular, translucent crystals of vitreous to adamantine luster, having one perfect and one fair cleavage. *Fracture*: conchoidal. *Hardness*: 2.5. *Specific gravity*: 5.3—5.45. *Tests*: B.B. on coal fades; fuses easily to a glass, and in reducing flame yields globule of lead and copper, from which much of the lead may be oxidized away, forming coating of oxide of lead. The remainder, treated with fused boric acid, gives copper globule. Decomposed by nitric acid. Alters to cerussite.

CROCOITE, lead chromate, $PbCrO_4$; lead 64 per cent, chromium 16.2 per cent. Monoclinic prismatic crystals, and granular and columnar. *Cleavage*: prismatic. Sectile. *Hardness*: 2.5—3. *Specific gravity*: 5.9—6.1. *Luster*: adamantine. *Color*: hyacinth-red. *Streak*: orange-yellow. *Diaphaneity*: translucent. *Tests*: B.B. in closed tube flies to pieces and blackens, but reddens on cooling; fuses very easily, and on coal is reduced to metallic lead, which burns, leaving residue of chromium oxide and giving yellow-lead coating. With borax and salt of phosphorus gives emerald-green beads (cold). With nitric acid forms yellow solution.

ZINC AND ZINC MINERALS

USES: Metallic zinc, as it comes from the refinery, is known as spelter. Sheet zinc has many uses in the industries. The metal is used for galvanizing iron; for making brass, bronze and other alloys; in the manufacture of telegraph batteries and other forms of batteries. Zinc oxide is used in the manufacture of rubber. Zinc sulphate is extensively used in dyeing and coloring yarns and fabrics. The chloride is used to some extent as a preservative of wood which is to be placed in the ground. Zinc pigments include zinc oxide, leaded zinc oxide, zinc-lead oxide and lithophone (described under barium).

Zinc salts are used in medicine.

ZINC MINERALS IMPORTANT AS ORES

SPHALERITE, ZINC BLENDE, BLENDE, BLACK-JACK, MOCK LEAD: Sulphide of zinc, ZnS; zinc 67 per cent. Often contains iron, manganese, cadmium, and other metals.

Color: yellow, brown, black; also green, red, white.

Luster: resinous to adamantine.

Diaphaneity: transparent to translucent.

Crystallization: isometric; often tetrahedrons.

Cleavage: perfect, dodecahedral.

Fracture: conchoidal. Brittle.

Hardness: 3.5—4.

Streak: brown to light yellow to white.

Specific gravity: 4.

Occurs: commonly massive, cleavable, coarse to fine granular and compact, sometimes amorphous.

Associations: lead minerals, pyrite, chalcopyrite, barite, fluorite, siderite, silver and gold ores.

Varieties: These are named for special colors and lusters: resin-jack, ruby-blende (ruby zinc), steel-jack.

Tests: The ordinary zinc reactions, and sulphur. Greenish to deep-green flame R.F. with soda on coal.

SMITHSONITE, ZINC CARBONATE, (DRY-BONE OF MINERS): Carbonate of zinc, $ZnCO_3$; zinc 52 per cent.

Color: white, greenish, grayish, brownish, green, blue, red, often iron-stained.

Luster: vitreous to pearly.

Diaphaneity: subtransparent to translucent.

Crystallization: hexagonal; seldom well crystallized.

Cleavage: good in one direction.

Fracture: uneven to conchoidal. Brittle.

Hardness: 5.

Streak: white.

Specific gravity: 4.3—4.4.

Occurs: botryoidal and kidney-shaped, stalactitic and in crystalline incrustations; granular. Often dry-bony-looking and iron-stained.

Tests: Effervesces in hydrochloric acid, especially warm; in closed tube gives off carbon dioxide, and is yellow hot and white when cold. Other zinc reactions.

Remarks: It is found more commonly in calcareous rocks in association with galena, sphalerite, calamine and calcite. Resembles calamine.

CALAMINE: A hydrous zinc silicate, sometimes called Smithsonite, $H_2Zn_2SiO_5$ or $(ZnOH)_2SiO_3$; zinc 54.15 per cent.

Color: white, sometimes greenish to bluish.

Luster: vitreous to almost pearly.

Diaphaneity: transparent to translucent.

Crystallization: orthorhombic; crystals often tabular, often grouped in sheaf-like forms in cavities. Hemimorphic.

Cleavage: good in two directions.

Fracture: uneven to subconchoidal. Brittle.

Hardness: 4.5—5.

Specific gravity: 3.4—3.5.

Occurs: massive, granular, botryoidal, fibrous, stalactitic. Smithsonite is commonly present.

Tests: Infusible, reacts for zinc, gelatinizes with acids. Does not effervesce. Heated in the O.F. with cobalt nitrate, becomes blue, while a coating around mineral may be green.

ZINCITE, RED ZINC ORE, RED OXIDE OF ZINC: Oxide of zinc, ZnO; zinc 80.24 per cent.

Color: deep red, also orange-yellow.

Luster: subadamantine.

Crystallization: hexagonal; crystals very rare.

Cleavage: good in one direction.

Fracture: nearly conchoidal, brittle.

Hardness: 4—4.5.

Streak: orange-yellow.

Specific gravity: 5.4—5.7.

Occurs: foliated, massive, or in coarse particles or grains; also granular.

Tests: Infusible. On coal with fluxes R.F. coats coal yellow hot, white cold; soluble in acids; other zinc reactions.

Remarks: Found as an ore with willemite, franklinite and hardystonite in Sussex County, New Jersey.

WILLEMITE, TROOSTITE: Silicate of zinc, Zn_2SiO_4 or $2ZnO.SiO_2$; zinc 58.5 per cent.

Color: white to greenish-yellow when pure; apple-green, flesh-red.

Luster: vitreous to resinous, not marked.

Diaphaneity: transparent to opaque.

Crystallization: hexagonal (rhombohedral); in prisms of varying length.

Cleavage: good in one direction.

Fracture: conchoidal to uneven. Brittle.

Hardness: 5.5.

Streak: not colored.

Specific gravity: 3.9—4.2.

Occurs: massive and disseminated in grains.

Tests: In forceps, glows and fuses with difficulty to white enamel. Powdered on coal R.F. gives yellow coating hot, white cold. Reacts with cobalt nitrate. Hydrochloric acid dissolves it and gives gelatinous silica.

FRANKLINITE: Compound of oxides of iron, zinc and manganese in varying proportions; $(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$.

Color: iron-black.

Luster: metallic to dull.

Diaphaneity: opaque.

Crystallization: isometric; with edges of crystals rounded and passing into rounded grains.

Cleavage: apparently in octahedrons, but is not a true cleavage.

Hardness: 5.5—6.5.

Streak: reddish-brown or black.

Specific gravity: 5.07—5.22.

Occurs: massive, granular, coarse or fine to compact. Octahedrons.

Tests: Borax bead gives amethyst color from manganese O.F. Is green in R.F.; fused with soda gives blue-green. Reacts for zinc with cobalt nitrate. Soluble in hydrochloric acid.

Remarks: Resembles magnetite, but is very weakly magnetic. Associated with zincite and willemite in Sussex County, New Jersey.

NICHOLSONITE ([1]) is a zinc-bearing aragonite containing zinc in varying amounts up to 10 per cent. When the mineral contains several per cent of zinc the luster becomes decidedly adamantine, the specific gravity may reach 2.99, and it shows a good pinacoidal cleavage. It occurs in radiating prismatic aggregates.

HETAEROLITE: A hydrous oxide of zinc and manganese, probably $2ZnO.2Mn_2O_3.H_2O$. (This is the mineral described as *Wolftonite* by Butler. Bull. 6, Colorado Geological Survey).

Color: dark brown to black, with a varnish-like exterior.

Luster: submetallic.

Diaphaneity: translucent to opaque.

Crystallization: possibly tetragonal; in radiating fibrous and prismatic bunches. Drusy.

Cleavage: possibly prismatic but not distinct.

Fracture: splintery.

Tenacity: brittle.

Hardness: 5.5 to 6.

Streak: dark chocolate brown.

Specific gravity: 4.6 to 4.9.

Occurrence: Associated with calamine and smithsonite as a vug-filling mineral in the Wolftone Mine, Leadville.

Tests: Reacts for zinc and manganese. Infusible. Soluble in hydrochloric acid yielding chlorine. Yields water in open tube.

ZINC MINERALS LESS IMPORTANT AS ORES

WURTZITE is a zinc sulphide, ZnS, but differing from sphalerite in crystal form. It occurs in hexagonal crystals, and fibrous, and massive. It is a *brownish-black mineral*, having a *resinous*

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[1] I am indebted to Professor G. M. Butler for the description of nicholsonite.

luster, brown streak, one fair cleavage, a hardness of 3.5—4, and a specific gravity of 4.0. *Tests*: same as for sphalerite.

GOSLARITE, zinc vitriol, is a hydrous sulphate of zinc, $ZnSO_4.7H_2O$, of white to yellowish and reddish color, formed by the disintegration of sphalerite, zinc blende. *Colorado locality*: at one time abundant on the old dumps containing zinc blende at Leadville.

HARDYSTONITE, a calcium-zinc silicate $Ca_2ZnSi_2O_7$, or $2CaO.ZnO.2SiO_2$. Occurs in limited amount as a fine-banded, granular ore associated with willemite, rhodonite and franklinite in the North Hill mine at Franklin Furnace, New Jersey.

GAHNITE, ZINC SPINEL, is a zinc aluminate, $ZnAl_2O_4$; zinc 35.5 per cent. Often contains manganese and iron. *Color*: various shades of green to almost black, bluish-black, grayish-brown and yellowish-brown. *Luster*: vitreous to greasy. *Crystallization*: isometric, octahedrons, dodecahedrons and modified cubes; also granular masses. Poor cleavage, conchoidal to uneven fracture, brittle. *Hardness*: 7.5—8.0. *Specific gravity*: 4—4.6. *Tests*: With fluxes on charcoal gives coating of zinc oxide; alone infusible; difficulty soluble in sulphuric acid.

HYDROZINCITE is a basic carbonate of zinc, perhaps $ZnCO_3.2Zn(OH)_2$. It occurs as massive, fibrous and earthy or frost-like incrustations as a result of the alteration of other zinc minerals. It was at one time found in the mines at Monarch and Garfield.

ZINC-BEARING MINERALS DESCRIBED UNDER OTHER METALS: Aurichalcite, Descloizite.

ZINC-BEARING MINERALS NOT DESCRIBED: Danalite, Hopeite, Voltzite.

TIN AND TIN MINERALS

USES: The most important use of tin is for plating metals, especially iron. Sheet iron coated with tin is known as sheet tin or tin plate, and is extensively used for roofing, for kitchen utensils, and for cans for preserving, storing and shipping foods, liquids, powders, etc. Many alloys contain tin. Some of the more important are: Britannia metal, an alloy of tin, antimony, copper, and sometimes zinc; solder contains tin and lead; bell-metal, gun-metal and bronze contain copper and tin. Phosphorus bronze is prepared by fusing copper and tin phosphide. An amalgam of tin and mercury is used in silvering mirrors. Tin oxide is used as a polishing powder. Stannic chloride is used as a mordant in dyeing.

MINERALS IMPORTANT AS ORES OF TIN

CASSITERITE, TIN STONE, TIN ORE: Tin dioxide, SnO_2; tin 78.6 per cent.

Color: remarkably variable. The commonest color is black to brownish-black, but brown, rust-red, yellow, gray and even white occur.

Luster: crystals usually brilliant, but the massive mineral is submetallic to adamantine.

Diaphaneity: varies from translucent to opaque; common ore is generally opaque.

Crystallization: tetragonal; low pyramids and prismatic forms with steep terminations.

Cleavage: rather poor.

Fracture: often smooth, subconchoidal, but commonly uneven. Brittle.

Hardness: 6—7.

Streak: varies with the color, but is rarely darker than pale brown.

Specific gravity: 6.8—7.1.

Occurs: As an ore it is commonly massive, granular, but kidney forms with radiating structure and an almost woody fibrous texture and wood color occur. As a placer deposit (stream tin), it is in angular, subangular and rounded grains, depending upon the amount of wear.

Tests: On coal with soda reduces to metallic tin and gives a thin white coating near the ore. Acids act on it very slowly.

Remarks: Cassiterite is most commonly found in acidic rocks, such as granite, greisen, and pegmatite, where it is commonly associated with quartz, tungsten minerals, mica, topaz, tourmaline, apatite, fluorite, and others.

STANNITE, TIN PYRITES, BELL-METAL ORE: A sulpho-stannate of copper, iron and sometimes zinc, Cu_2FeSnS_4 or $Cu_2S.FeS.SnS_2$; tin 27.5 per cent, copper 29.5 per cent, iron 13.1 per cent.

Color: steel-gray when pure; iron-black, bronzy when mixed with chalcopyrite.

Luster: metallic.
Diaphaneity: opaque.
Crystallization: isometric-tetrahedral.
Cleavage: poor.
Fracture: uneven. Brittle.
Hardness: 4.
Streak: blackish.
Specific gravity: 4.3—4.5.
Tests: On coal in O.F. fuses to globule, gives off sulphur and coats coal with dioxide of tin, SnO_2. Roasted mineral reacts for iron and copper with borax. With nitric acid gives blue solution.

TIN-BEARING MINERALS NOT DESCRIBED: Cylindrite, Teallite, Franckeite, Nordenskiöldine. Tin is often found in niobates, tantalates and tungstates.

ALUMINUM AND ALUMINUM MINERALS

USES: Metallic aluminum is extensively used for kitchen utensils and for ornamental purposes. Aluminum wire is used as an electrical conductor, but its efficiency is only about 60 per cent that of copper. A small amount is used for printing and lithographing. Powdered aluminum is extensively used in metallurgical reduction, especially in the steel industry; and in the welding of large bars of steel, such as steel rails, etc. Alloys of aluminum and copper, zinc and other metals are in commercial use.

Aluminum sulphate is extensively used as a mordant (in place of the alums which were formerly used), in dyeing cotton, wool, silk, and other textile materials. It is also much used in carbonizing wool contaminated with vegetable matter. In the paint industry it is used in the manufacture of the lake pigments. Prussian blue, Thenard blue, yellow, and Indian yellow.

Much aluminum sulphate is used in the hide and leather industry; in paper-making, plaster-hardening, and lime washes; in rendering combustible materials non-inflammable; in purifying water, and in sanitary engineering; in bleaching, photography and medicine; in certain baking powders, and in sugar refining.

Alums are double sulphates of aluminum and a base, such as potassium, sodium and ammonium. They were formerly much used as mordants in the textile industries, but aluminum sulphate has largely replaced them. They are used in tanning, in the manufacture of hard plasters, and in the making of baking powders.

Other aluminum salts are used to a less extent.

Aluminum is the most abundant of the metals in the rocks of the earth, but comparatively few of the minerals containing it are, at present, possible sources of the metal, on account of the difficulty of separating it from its ores.

THE ORES OF ALUMINUM

BAUXITE, BEAUXITE: Probably variable, from $Al_2O_3.3H_2O$, to $Al_2O_3.2H_2O$, and $Al_2O_3.H_2O$. These would give, respectively, aluminum 34.6, 39.1 and 45.0 per cent.

Color: whitish, grayish, yellowish, brownish.
Luster: dull, earthy.
Diaphaneity: opaque.
Crystallization: not crystallized.
Cleavage: none; concentric parting frequent.
Fracture: smooth to uneven.
Tenacity: brittle.
Hardness: variable, but usually low, 1—3.
Streak: white to pale yellowish.
Specific gravity: 2.5.
Occurs: oolitic, pisolitic, granular, earthy.
Tests: Infusible; deep blue with cobalt nitrate. Yields water at high temperature in closed tube; difficultly soluble in hydrochloric acid.
Uses: the chief ore of aluminum; the manufacture of aluminum sulphate, alums and other aluminum salts; refractory linings for furnaces and crucibles; the manufacture of alundum, an artificial corundum used as an abrasive; alumino-ferric cake, a by-product of the metallurgy of aluminum, used in sanitation.

ALUNDUM is an artificial corundum (Al_2O_3) produced by calcining and fusing bauxite. It is crushed and used as an abrasive; and lately as a refractory lining for furnaces. It fuses at 2,300° C.

CORUBIN is an abrasive material produced from the slag resulting from the reaction between aluminum and chromium oxides. It contains only a trace of chromium.

GIBBSITE, HYDRAGILLITE: Aluminum hydrate, $Al(OH)_3$ or $Al_2O_3.3H_2O$; aluminum 34.6 per cent.

Color: white, grayish, greenish or reddish, occasionally yellow.

Luster: vitreous to pearly.

Diaphaneity: translucent.

Crystallization: monoclinic; tabular, approaching hexagonal outline.

Cleavage: one good.

Fracture: irregular.

Tenacity: tough to brittle.

Hardness: 2.5—3.5.

Streak: white.

Specific gravity: 2.3—2.4.

Occurs: thin crusts, stalactites, mammillary forms, sometimes poorly fibrous.

Association: bauxite, limonite.

Tests: Infusible, glows, exfoliates, becomes white, yields water in closed tube. With cobalt nitrate gives deep blue. Soluble in strong sulphuric acid.

Remarks: A very desirable ore of aluminum, but not known in commercial quantities.

CRYOLITE: A fluoride of sodium and aluminum, Na_3AlF_6; aluminum 12.8 per cent, fluorine 54.4 per cent, sodium 32.8 per cent.

Color: snow-white to colorless, sometimes reddish, or brownish to red, and occasionally black.

Luster: greasy to vitreous to pearly.

Diaphaneity: transparent to translucent.

Crystallization: monoclinic; crystals often cubical and grouped in parallel position.

Cleavage: three, good.

Fracture: uneven.

Tenacity: brittle.

Hardness: 2.5.

Streak: white.

Specific gravity: 2.95—3.0.

Occurs: mainly massive, cleavable, chiefly in granite.

Tests: Very easily fusible, coloring the flame yellow. On coal, fuses to clear bead, opaque when cold. After long blowing, the bead spreads out and the fluoride of sodium sinks into the coal, and fluorine is given off and residue of alumina, Al_2O_3, is left, which with cobalt nitrate O.F. gives blue color. Soluble in sulphuric acid, yielding hydrofluoric acid.

Remarks: The only cryolite deposit of commercial importance in America is in Greenland.

Uses: The most important uses are in the manufacture of opaque glass for enameling iron ware; in the production of aluminum from bauxite by the electric furnace, and as a flux in the manufacture of white Portland cement.

Colorado localities: It has been found in Pikes Peak region in such quantities as to justify search for commercial deposits. Elsewhere in the state it is known only in rare crystals and grains.

ALUMINUM-BEARING MINERALS DESCRIBED ELSEWHERE: Corundum, Diaspore, Feldspars, Nephelite, Leucite, Topaz, Cyanite, Kaolinite, and other minerals of the Kaolinite group; the Zeolites, Lazulite, Turquoise and others.

THALLIUM AND THE SOURCES OF THALLIUM

USES: As yet there are but few uses for thallium. It is used in place of lead in the manufacture of a glass of high refractory power used in certain optical instruments. A small amount of thallium is added to the tungsten filament used in the nitrogen-tungsten lamp to prevent the volatilization of the tungsten and the "smoking" of the glass of the bulb. Certain thallium salts are used in medicine. Thallium silver nitrate is a clear liquid having a specific gravity of 4.8, used for the determination of the specific gravities of mineral fragments, gems and small crystals.

SOURCES: Minerals in which thallium is an essential constituent are very rare.

Crookesite, $(Cu,Tl,Ag)_2Se$, contains 16–19% Tl.

Lorandite, $TlAsS_2$, contains 59–60% Tl.

Hutchinsonite, $(Tl,Ag,Cu)_2S.As_2S_3PbS.As_2S_3$, contains 18–25% Tl.

Vrbaite, $TlAs_2SbS_5$, contains 32.15% Tl.

It occurs in many pyrites, some zinc-blendes and chalcopyrite. The metal is highly volatile and in the treatment of pyrite, zinc-blende and chalcopyrite in metallurgical processes it passes over into the dust chambers and into the bag houses. In the making of sulphuric acid from pyrite the thallium is caught in the "chamber mud." It is separated from the flue dust and the chamber mud by chemical processes.

Colorado: A considerable quantity of thallium is saved from the treatment of zinc and lead ores, and is probably the only American production of the metal.

THALLIUM MINERALS

CROOKESITE: A selenide of copper and thallium with a small amount of silver, $(Cu,Tl,Ag)_2Se$. A massive, compact, lead-gray mineral with no trace of crystallization, a hardness of 2.5–3, a specific gravity of 6.9, and a metallic luster. Fuses very easily to a greenish-black shining enamel, coloring the flame strongly green. Soluble in nitric acid, insoluble in hydrochloric.

LORANDITE: A sulpharsenide of thallium, $Tl_2S.As_2S_3$. A fine red translucent to transparent mineral, often tarnished to lead-gray or covered with an ochre-yellow powder. The streak is dark cherry-red, the cleavage good in three directions, yielding in one direction flexible plates. The crystallization is monoclinic in highly modified tabular or prismatic forms. On charcoal fuses easily and volatilizes coloring the flame bright green and yielding arsenic fumes. In closed tube fuses and yields a black sublimate of thallium sulphide, and an orange sublimate of arsenic. Soluble in nitric acid. Resembles realgar with which it associates.

HUTCHINSONITE: Composition, $(Tl,Ag,Cu)_2S.As_2O_3+PbS.As_2O_3$?, Thallium 18–25 per cent. An *orthorhombic* mineral of scarlet to deep cherry red, occurring in flattened rhombic prisms with numerous small domes and pyramids. *Cleavage,* good. *Hardness,* 1.5–2. *Luster,* adamantine. Streak, scarlet to cherry-red. Transparent to translucent.

VRBAITE: Composition, $TlAs_2SbS_5$. *Orthorhombic,* in tabular and pyramidal forms. In large masses it is gray-black, and opaque, but in thin splinters it is dark red and translucent to transparent. The streak is light yellowish red. *Luster,* submetallic to metallic. *Fracture,* uneven to conchoidal. *Hardness,* 3.5. *Cleavage,* good. It is associated with orpiment and realgar. See Arsenic Minerals.

None of the thallium minerals is known in commercial quantity. Prospectors would be justified in looking for them in all parts of the Sulphide Belt, especially in the La Plata and San Juan mountains, and other places where tennantite, tetrahedrite (gray copper), ruby silver and such ores are found.

GOLD AND GOLD MINERALS

USES: The chief uses of gold are in coinage, gold plate, gold plating and jewelry manufacture. Coin gold is 9 parts of gold to 1 part of copper. The gold used in jewelry, watch-cases, etc., varies from ten carats to eighteen carats fine—that is, ten twenty-fourths to eighteen twenty-fourths fine. It is also used for vessels in the chemical industry.

GOLD MINERALS IMPORTANT AS ORES

GOLD: Metallic gold, Au, but commonly alloyed with silver, and occasionally with copper, iron and the rarer metals.

Color: gold-yellow, sometimes paler.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: isometric; perfect crystals are rare, but distorted and skeleton crystals are not especially uncommon.

Cleavage: none.

Fracture: hackly.

Tenacity: very malleable and ductile.

Hardness: 2.5—3.

Streak: gold-yellow, sometimes paler.

Specific gravity: 15.6—19.3.

Occurs: (a) In scattered grains, scales and plates in veins and other forms of ore-bodies in rocks of various ages and characters, from the most ancient metamorphic to the most recent volcanic rocks. Within the veins the commonest mineral-containers of gold are quartz, pyrite, arsenopyrite, chalcopyrite, stibnite. It is also found in sphalerite, pyrrhotite, and in various copper ores such as chalcocite, enargite and others. (b) In placer deposits, the gold of which has been derived from veins, and concentrated by stream action.

Tests: Fuses easily at 1,100° C; not affected by fluxes or single acids, but completely soluble in aqua regia, if pure. If much silver is present, the separation is incomplete.

SYLVANITE, GRAPHIC TELLURIUM: A telluride of gold and silver; $(Au,Ag)\ Te_2$ with Au:Ag=1:1, or gold 24.5 per cent and silver 13.4 per cent.

Color and streak: silver-white, occasionally steel-gray, tarnishing to yellowish.

Luster: brilliant metallic.

Diaphaneity: opaque.

Crystallization: monoclinic; prismatic and thin tabular.

Cleavage: one perfect.

Fracture: uneven.

Tenacity: brittle.

Hardness: 1.5—2.

Specific gravity: 7.9—8.3.

Occurs: crusts and filling seams; arborescent forms resembling written characters; bladed or platy crystals and granular-crystalline masses.

Associations: other tellurides, such as calaverite, krennerite; fluorite, quartz, etc.

Tests: On charcoal, fuses to gray globule, depositing a white coating which disappears R.F., coloring the flame bluish-green. Long heating will bring yellow gold-silver globule, soluble in aqua regia, forming curd-like mass of silver chloride. Open tube gives sublimate (gray near assay), which melts to clear transparent drops. The powdered mineral heated in strong sulphuric acid gives a fine violet to purple solution.

CALAVERITE: A telluride of gold, $AuTe_2$, in which, as a rule, silver replaces some of the gold; gold about 40 per cent.

Color: silver-white to steel-gray to pale bronze-yellow.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: monoclinic; prismatic or lath-shaped, striated crystals.

Cleavage: none.

Fracture: uneven.

Tenacity: brittle.

Hardness: 2.5.

Streak: Same as color.

Specific gravity: 9.043.

Occurs: crusts, druses or matted crystals, massive, granular.

Associations: petzite, sylvanite, fluorite, quartz and hornstone.

Tests: On coal fuses, gives a white sublimate, and ultimately a metallic gold bead. The sublimate colors the R.F. green and disappears. In open tube forms white sublimate, which melts to clear transparent drops. Soluble in nitric acid and in strong sulphuric acid; the latter solution is intense purple.

Remarks: Calaverite is much like sylvanite, but contains less silver. Krennerite has the same composition as calaverite, but crystallizes in the orthorhombic system.

GOLD MINERALS LESS IMPORTANT AS ORES

NAGYAGITE, a sulpho-telluride of lead and gold, with antimony. It is a blackish lead-gray, opaque mineral, having a brilliant metallic luster, a hardness of 1—1.5, a specific gravity of 6.85—7.2, a blackish lead-gray streak, one perfect cleavage; occurring in tabular crystals with striated faces, and in foliated granular masses. *Tests*: B.B. on charcoal forms two coatings—one of antimonate, tellurate and sulphate of lead, and easily volatile; the other, near the mineral, consists of lead oxide and is less volatile. If heated a long time in O. F., a gold bead results. Decomposed by aqua regia.

KRENNERITE is a gold-silver telluride, $(Au,Ag)Te_2$, probably approaching calaverite in composition rather than sylvanite. It is a silver-white to brass-yellow, opaque mineral of metallic luster, one perfect cleavage, a subconchoidal fracture; occurring in orthorhombic crystals having striated prisms. *Tests*: same as for sylvanite; decrepitates violently. *Colorado*: Independence mine and others in the Cripple Creek district.

PETZITE is a telluride of silver and gold $(Ag,Au)_2Te$, of steel-gray to iron-black color, metallic luster, subconchoidal fracture, a hardness of 2.5—3, a specific gravity of 8.7—9; occurring in fine granular to compact masses. *Tests*: the same as for hessite, but the globule contains both silver and gold. *Colorado*: several mines in Boulder County, especially the Red Cloud; and the Gold King mine, Cripple Creek.

GOLD-BEARING MINERALS DESCRIBED UNDER OTHER METALS: Pyrite, Arsenopyrite, Chalcopyrite, etc., are frequently gold-bearing. See description of native gold.

SILVER AND SILVER MINERALS

USES: The chief uses of silver are for coins, domestic and ornamental objects. Pure silver is rarely used even in coinage. American silver coins contain 10 per cent of copper. Silver salts are much used in photography, in certain chemical processes, and to a limited extent in medical science. A small amount is used for vessels of various kinds in the chemical industry.

SILVER MINERALS IMPORTANT AS ORES

SILVER: Metallic silver, Ag, usually alloyed with gold and copper.

Color and streak: silvery-white, but readily tarnished.
Luster: metallic.
Crystallization: isometric, in acicular forms, distorted cubes, etc.
Cleavage: none.
Fracture: hackly.
Tenacity: ductile, malleable.
Hardness: 2.5—3.
Specific gravity: 10.1—11.1.
Occurs: flakes, scales, plates, wire and mossy forms in veins; also in minute grains in galena.
Tests: On coal fuses readily to white, metallic globule, crystallizing on cooling. Soluble in nitric acid, and deposited again on metallic copper. Precipitated from solution by hydrochloric acid as curdy silver chloride.

ARGENTITE, SILVER GLANCE: Sulphide of silver, Ag_2S; silver 87.1 per cent.
Color: blackish lead-gray.
Luster: dull metallic.
Crystallization: isometric; cubes, octahedrons.
Cleavage: poor.
Fracture: smooth, curved.
Tenacity: sectile.
Hardness: 2—2.5.
Streak: shining, blackish-gray.
Specific gravity: 7.2—7.36.
Occurs: crusts and coatings, massive and arborescent forms, sometimes connected by threads of native silver.
Tests: In open tube gives sulphur fumes. On coal, swells, fuses, gives sulphur fumes and globule of silver. Soluble in nitric acid.

ACANTHITE: A silver sulphide, Ag_2S. It crystallizes in the orthorhombic system, in slender prismatic and wire-like crystals, having an indistinct cleavage, an uneven fracture, a hardness of 2—2.5, a specific gravity of 7.2 to 7.3, an iron-black color and a metallic luster. It is sectile.

Colorado: Georgetown and Rico mines.

SILVER-BEARING GALENA, ARGENTIFEROUS GALENA: Much of the silver of commerce is obtained from silver-bearing galena, in which it is believed to occur in minute metallic grains, and in the form of argentite, Ag_2S. The finer-grained galena is more commonly silver-bearing than is the coarse-grained.

STROMEYERITE, argentiferous sulphide of copper, or sulphide of silver and copper, $(Ag,Cu)_2S$, or $Ag_2S.Cu_2S$; silver 53.1 per cent, copper 31.1 per cent. It is a dark steel-gray, opaque mineral, having a metallic luster, a steel-gray streak, a hardness of 2.5—3, a specific gravity of 6.15 to 6.3, and occurring in orthorhombic prisms, also massive, compact. *Tests*: In closed tube fuses without sublimate. Sulphurous fumes in open tube. B.B. on charcoal forms a bead which reacts for copper, and when cupelled with lead yields a silver globule. *Colorado*: in certain Silverton mines.

PYRARGYRITE, RUBY SILVER ORE, DARK RED SILVER ORE: A sulph-antimonide of silver, Ag_3SbS_3 or $3Ag_2S.Sb_2S_3$; silver 59.9 per cent, antimony 22.3 per cent.

Color: black, deep red by transmitted light. Thin edges show the red.

Luster: metallic, adamantine.

Diaphaneity: transparent or translucent in thin splinters, opaque in thicker pieces.

Crystallization: rhombohedral; prismatic.

Cleavage: fair.

Fracture: conchoidal to uneven. Brittle.

Hardness: 2.5.

Streak: purplish-red.

Specific gravity: 5.77—5.86.

Occurs: massive, compact, commonly associated with proustite, cerargyrite, other silver ores, galena, pyrite and sphalerite.

Tests. On coal fuses with spurting to globule of silver sulphide, which may be oxidized, O.F., or reduced with soda R.F., to silver. Forms white sublimate on coal. Closed tube, forms black sublimate, red when cold. Soluble in nitric acid, with separation of sulphur and antimony trioxide.

PROUSTITE, RUBY SILVER ORE, LIGHT-RED SILVER ORE: A sulph-arsenide of silver, Ag_3AsS_3; silver 65.4 per cent, arsenic 15.2 per cent.

Color: scarlet-vermilion.

Luster: adamantine.

Diaphaneity: transparent to translucent.

Crystallization: hexagonal; rhombohedral or scalenohedral forms.

Cleavage: rhombohedral, distinct.

Fracture: conchoidal to uneven.

Tenacity: brittle.

Hardness: 2—2.5.

Streak: scarlet to aurora-red.

Specific gravity: 5.57—5.64.

Occurs: crystals and crystal crusts; also massive and compact.

Associations: other silver ores and sulphides of other metals, such as iron, zinc and lead.

Tests: On coal, fuses, giving odor of arsenic and sulphur; R.F. with soda gives silver globule. Closed tube, fuses and forms faint-red sublimate, yellow when cold. Open tube, sulphur fumes and crystalline arsenic trioxide.

Remarks: Found at Ruby in Gunnison County, in Ouray and San Miguel Counties.

STEPHANITE, BRITTLE SILVER ORE: A sulph-antimonide of silver, Ag_5SbS_4 or $5Ag_2S.Sb_2S_3$; silver 68.5 per cent, antimony 15.2 per cent.

Color: iron-black.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: orthorhombic; short, prismatic, tabular.

Cleavage: poor.

Fracture: subconchoidal to uneven.

Tenacity: brittle.

Hardness: 2—2.5.

Streak: iron-black.

Specific gravity: 6.2—6.3.

Occurs: Crystals are not common, but disseminated grains and massive and fine-grained compact forms are most abundant.

Associations: other silver ores, and sulphides of other metals.

Tests: On coal, fuses readily, coating the coal and giving out white fumes with the odor of sulphur dioxide, and yielding a silver bead. Open tube, fuses and gives sulphur and antimony fumes. Closed tube, decrepitates, fuses. Soluble in nitric acid, with separation of sulphur and antimony trioxide, Sb_2O_3.

POLYBASITE, a sulphantimonite of silver, Ag_9SbS_6 or $9Ag_2S.Sb_2S_3$; silver 75.6 per cent with, usually, a little copper. It is an iron-black to faintly reddish-black mineral of metallic luster, black streak, imperfect cleavage, uneven fracture, occurring in short, six-sided, tabular prisms. *Tests*: Open tube fuses, gives sulphur and antimony fumes and a white sublimate of antimony trioxide. B.B. fuses and spurts, forming a globule, giving off sulphur fumes and coating of antimony trioxide. Decomposed by nitric acid. *Colorado localities*: Telluride and Rico mines, and at various places in the sulphide belt, particularly in Clear Creek County.

ARGENTIFEROUS TETRAHEDRITE, FREIBERGITE: The color is generally lighter than that of tetrahedrite proper, inclining to steel-gray, but is sometimes iron-black. The streak is often reddish. The percentage of silver ranges from 3 to 30 or over. It is a somewhat common ore in the San Juan and the sulphide belt in general, though much of the ore called argentiferous tetrahedrite is argentiferous tennantite.

ARGENTIFEROUS TENNANTITE: The tennantite of Colorado is commonly silver-bearing, and some analyses are said to show as high as 25 per cent silver. The argentiferous variety is not readily distinguished from the common tennantite, except by analysis.

CERARGYRITE, HORN SILVER: AgCl; silver, 75.3 per cent.

Color: pearl gray to yellowish-gray, to whitish, rarely violet; violet-brown on exposure to light.

Luster: waxy to resinous.

Diaphaneity: transparent to translucent.

Crystallization: isometric; cubes.

Cleavage: none.

Fracture: somewhat conchoidal.

Tenacity: very sectile.

Hardness: 1—1.5.

Streak: shining white.

Specific gravity: 5.55.

Occurs: usually massive and resembling wax, often as crusts; sometimes as aborescent strings; mainly in upper workings of mines.

Associations: oxidized products in the upper parts of veins, especially with iron oxides, barite and calcite.'

Tests: Fuses easily, yielding acrid fumes and a silver globule. On coal with salt of phosphorus and copper oxide gives fine azure-blue flames. Not soluble in acids; soluble in ammonia. Rubbed on a moistened surface of zinc or iron, it swells, blackens, and the surface of zinc is silvered, and the mineral is reduced to spongy metallic silver.

Remarks: It is probably always secondary, and may be deposited from solution by the chlorides of surface waters.

EMBOLITE, chloride-bromide of silver, $Ag(Cl,Br)$, is a yellow to green, sectile mineral of resinous to adamantine luster, having a hardness of 1—1.5, a specific gravity of 5.3—5.4, occurring in concretionary, encrusting masses. It closely resembles cerargyrite, bromyrite and iodyrite, and occurs under the same conditions and from the same causes.

SILVER MINERALS OF LESS IMPORTANCE AS ORES

AMALGAM is a native alloy of silver and mercury varying from Ag_2Hg_3 to $Ag_{36}Hg$. It is an opaque, silver-white mineral of brilliant metallic luster, poor cleavage, conchoidal fracture, a hardness of 3—3.5, a specific gravity of 13.75—14.1, a silver white streak; occurring in scales, plates, crusts, and occasionally dodecahedral crystals. *Tests*: Heated on charcoal the mercury is driven off and a globule of silver is left. Rubbed on copper gives silvery luster.

HESSITE: A telluride of silver, Ag_2Te; silver 63.28 per cent; gold often replaces part of the silver.

Color: lead-gray to steel-gray.

Luster: metallic.

Crystallization: isometric; in modified and distorted crystals.

Cleavage: poor.

Fracture: even.

Tenacity: slightly sectile.

Hardness: 2.5—3.

Streak: black.

Specific gravity: 8.31—8.45.

Occurs: modified and distorted crystals; also massive compact or fine-grained, in the Stanislaus mine in California, the Red Cloud mine, Boulder County, and the Kearsarge mine, Utah.

Tests: Open tube, a faint sublimate of tellurium dioxide, which fuses B.B. to colorless globules. On coal, fuses to black globule which sprouts points of silver on cooling. With soda, gives silver globule. The powder gives fine purple with strong sulphuric acid.

EMPRESSITE: A silver telluride having the formula AgTe; silver 45.17, tellurium 54.75 per cent.

Color: pale bronze.
Luster: metallic.
Diaphaneity: opaque.
Crystallization: not determined.
Cleavage: not observed.
Fracture: finely conchoidal to uneven.
Tenacity: brittle to friable.
Hardness: 3—3.5.
Streak: grayish black to black.
Specific gravity: 7.51.
Occurs: very fine granular and compact masses associated with galena and native tellurium in the Empress Josephine mine, Bonanza District, Saguache County, Colorado.
Tests: B.B. fuses at 1 to a metallic globule of metallic luster. In O.F. gives heavy white coating of tellurium dioxide and a sprouting globule of metallic silver. Readily soluble in nitric acid; less readily in sulphuric. In the open tube a faint white sublimate of tellurium dioxide is formed which, when strongly ignited, fuses to colorless globules. When the concentrated sulphuric acid solution is cooled a heavy deposit of minute colorless, tabular crystals forms. These are readily soluble in dilute sulphuric acid and in water. On charcoal they yield a globule of silver.

BROMYRITE, silver bromide, AgBr; silver 57.4 per cent, bromine 42.6 per cent. It is a bright-yellow to greenish-yellow to grass- or olive-green mineral, having a resinous to adamantine luster, a hardness of 2—3, a specific gravity of 5.8—6, an uneven fracture, but no cleavage. It usually occurs in small concretions. Like cerargyrite and iodyrite, it is sectile. *Occurrence*: essentially the same as iodyrite and cerargyrite. *Tests*: In closed tube and with metallic zinc reacts like cerargyrite. B.B. on charcoal gives irritating bromine fumes and a globule of silver. In bulb-tube with potassium bisulphate gives yellowish-brown bromine vapors. Insoluble in nitric acid. Difficultly soluble in ammonia.

IODYRITE, silver iodide, AgI; silver 46 per cent. *Color*: various shades of yellow to yellowish-green and brownish. *Luster*:

resinous to adamantine. *Diaphaneity*: translucent. *Crystallization*: hexagonal prisms, thin plates, and massive. *Cleavage*: one perfect. *Tenacity*: sectile, plates flexible; soft. *Specific gravity*: 5.6—5.7. *Streak*: yellow. *Occurrence*: secondary, from the alteration of ores of silver. Found in upper workings of mines as a result of the action of descending waters carrying iodine in solution. *Tests*: In closed tube fuses and turns deep orange, but cools to its normal color. B.B. on charcoal gives purplish fumes of iodine and leaves a globule of silver. Fused with potassium bisulphide in bulb-tube gives iodine fumes.

GALENOBISMUTITE, variety ALASKAITE, is a silver-bearing sulphide of lead and bismuth, $PbS.Bi_2S_3+Ag$. It is a dark to light gray to tin-white opaque mineral having a grayish black streak, a metallic luster, a hardness of 3 to 4, a specific gravity of 6.88 to 7.15. It fuses easily on charcoal giving lead and bismuth coatings. Readily soluble in strong nitric acid.

Colorado: Alaska mine, Poughkeepsie Gulch, where it is associated with quartz, barite, chalcopyrite and tetrahedrite.

SILVER-BEARING MINERALS DESCRIBED UNDER OTHER METALS: Sylvanite, Calaverite, Krennerite, Petzite, Galena.

The following minerals are frequently silver-bearing: Sphalerite, Pyrite, Chalcopyrite, Chalcocite and other copper ores.

SILVER-BEARING MINERALS NOT DESCRIBED: Dyscrasite, Matildite, Miargyrite, Pearceite, Polyargyrite, Argyrodite, Canfieldite.

PLATINUM, IRIDIUM, OSMIUM, PALLADIUM

USES OF PLATINUM: The most important use of the metal platinum is in the manufacture of chemical apparatus, such as crucibles, dishes, stills, spoons, wire, foil, etc. Platinum wire and foil or sheet platinum, an alloy of platinum and iridium, are extensively used in the electrical industry for supporting the filaments and mantles of incandescent lamps, for electrolitic anodes for contacts in induction apparatus, electric bells, etc.

In the manufacture of sulphuric acid, chlorine, alkalies, lyes, and chlorates, platinum is almost indispensable. In the construction of electrical furnaces, and apparatus for measuring high temperatures, such as the resistance thermometer, platinum is much used.

Potassium chloro-platinate is used in photography. Hydrochlor-platinic acid is much used in chemistry. As a catalytic agent, finely divided platinum is extensively used in the sulphuric-acid industry and other chemical work. The use of platinum in the jewelry trade is increasing.

USES OF IRIDIUM: Most of the iridium produced is mixed with platinum to form an alloy which is harder than platinum, and more resistant to aqua regia. An alloy containing 30 per cent iridium is not attacked by aqua regia. A small amount is used for making standard weights, pivots, contact points, points of fountain pens, and in certain high-temperature work. The oxide, iridium black, is used in china-painting.

USES OF OSMIUM: The only present use is in the filaments of certain forms of electric lamps.

USES OF PALLADIUM: It has many uses which require only a small amount, but if the supply were assured its use would rapidly increase. Alloys used in dentistry take the bulk of palladium consumed in this country. Other uses are: for the circles of astronomical instruments, certain delicate parts of watches, soldering platinum.

SOURCES OF THE METALS OF THE PLATINUM GROUP

PLATINUM: An alloy of platinum, iridium, rhodium, palladium and often osmium, with varying amounts of iron, copper and gold.

Color and streak: whitish steel-gray; shining.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: isometric; crystals rare.

Cleavage: none.

Fracture: hackly.

Tenacity: malleable and ductile.

Hardness: 4—4.5.

Specific gravity: of the native alloy, 14—19; pure platinum, 21—22.

Occurs: nuggets, grains and scales, chiefly in placer deposits. The Russian platinum placers are the result of the disintegration of platinum-bearing peridotite.

Rocks: mainly peridotites.

Tests: Infusible; not affected by borax or salt of phosphorus, except in state of fine dust, when reactions for copper and iron may be obtained. Soluble in hot aqua regia.

For further tests, see page 267.

SPERRYLITE: Platinum arsenide. $PtAs_2$; platinum 56.5 per cent. Antimony and rhodium are commonly present.

Color: tin-white.

Luster: metallic, brilliant.

Diaphaneity: opaque.

Crystallization: isometric; cubes and cubo-octahedrons: also in irregular grains of small size.

Fracture: conchoidal. Brittle.

Hardness: 6—7.

Streak: black.

Specific gravity: 10.602.

Occurrence: mainly in small irregular grains, but also in small well-formed crystals.

Associations: pyrite, chalcopyrite, cassiterite, nickeliferous pyrrhotite, covellite, etc. Palladium ores are found with it in the Rambler mine.

Tests: In closed tube unchanged; in open tube readily yields sublimate of arsenic trioxide; if heated slowly in open tube does not melt, but when rapidly heated melts easily. Melts readily when placed on red-hot platinum, forming small, porous sprouts.

Economic: ore of platinum, saved at Rambler mine in Wyoming, and the Sudbury district, Ontario.

IRIDIUM, alloyed with platinum and other related metals. It is a silver-white metal (or alloy), with a tinge of yellow on the surface and a metallic luster. It occurs mainly in irregular grains, but occasionally in cubes. It has an indistinct cleavage, a ragged fracture, a hardness of 6—7, a specific gravity of 22.65—22.84, and is somewhat malleable. Found in placer washings with platinum and occasionally gold.

IRIDOSMINE is an alloy of the metals iridium and osmium, generally with more or less platinum and related metals. It occurs in lustrous, tin-white to steel-gray, irregular flattened grains of perfect cleavage, and occasionally in hexagonal prisms. It has a hardness of 6—7, and a specific gravity of 19.3—21.12. The proportions of the two metals vary widely. It occurs in placer washings with platinum and gold.

LAURITE, a sulphide of ruthenium and osmium, probably essentially RuS_2 with a small percentage of osmium. It occurs in rounded octahedrons, spherical forms and grains. It is a bright, opaque, brittle, metallic mineral of dark iron-black color, dark-gray streak, distinct cleavage, subconchoidal fracture, hardness of 7.5, and specific gravity of 7.0. *Tests*: B.B. decrepitates, infusible, gives sulphurous and then osmic fumes. Not acted upon by aqua regia, nor by heating with potassium disulphate. Found in platinum placer washings. Reported from Oregon.

PALLADIUM is a malleable and ductile metal of metallic luster and whitish steel-gray color, commonly alloyed with a little platinum and iridium. It occurs in grains, sometimes composed of diverging fibers, and in minute octahedrons. It is opaque, has a hardness of 4.5—5, and a specific gravity of 11.3—11.8. It is more fusible than platinum, osmium and iridium. Oxidizes at a lower temperature than silver and is not blackened by sulphurous fumes. It occurs in the Rambler mine, Wyoming, with sperrylite and covellite.

ARSENIC AND ARSENIC MINERALS

USES: The trioxide, As_2O_3, white arsenic, is used in the manufacture of glass, and as a constituent of certain pigments, such as Paris green, Scheele's green, Paris purple, London purple, English purple, and others. It is used in various forms for destroying insects and other animal pests. In tanning and taxidermy arsenic salts are used as preservative agents. Other arsenic salts are used in dyeing and calico-printing. Certain salts are used in medicines, and others in chemical preparations for laboratory use. Realgar mixed with saltpeter burns with a brilliant white light and is used in fireworks.

The oxide is also extensively used for destroying weeds, especially along railways. The metal is used to a limited extent in the manufacture of shot, and is supposed to make it rounder and harder.

ORES AND OTHER MINERALS OF ARSENIC

REALGAR: Arsenic monosulphide, AsS; arsenic 70.1 per cent.

Color: aurora-red or orange-yellow.

Luster: resinous.

Diaphaneity: transparent to translucent.

Crystallization: monoclinic; in short prismatic crystals vertically striated.

Cleavage: pinacoidal good.

Fracture: small conchoidal.

Tenacity: sectile.

Hardness: 1.5—2.

Streak: same as color.

Specific gravity: 3.556.

Occurrence: in crystals, but more commonly in coarse or fine granular masses, sometimes forming incrustations. In metalliferous veins and hot-spring deposits.

Associations: orpiment, ores of silver and lead, calcite.

Tests: Closed tube, melts, volatilizes, giving transparent red sublimate. In open tube, slowly heated, sulphur fumes and white arsenic trioxide. B.B. on charcoal burns with blue flame and odors of sulphur and arsenic. Soluble in caustic alkalies.

Colorado localities: La Plata quadrangle.

Uses: mainly in fireworks. A mixture of realgar and saltpeter gives a brilliant white light.

ARSENIC, Native Arsenic: Metallic arsenic, often containing a small amount of antimony and traces of iron, silver, gold or bismuth.

Color: tin-white, but tarnishing to a submetallic dark gray.

Luster: nearly metallic.

Diaphaneity: opaque.

Crystallization: rhombohedral; crystals are rare.

Cleavage: basal perfect, rhombohedral fair.

Fracture: uneven and fine granular, sometimes subconchoidal. Brittle.

Hardness: 3.5.

Streak: tin-white.

Specific gravity: 5.63—5.73.

Occurrence: usually granular, massive, often layered, and sometimes showing botryoidal surfaces. Found mainly in crystalline and metamorphic rocks.

Associations: ores of antimony, ruby silver, realgar, sphalerite.

Tests: B.B. on charcoal volatilizes without fusing and deposits white arsenic trioxide, As_2O_3, to some distance from the assay. Gives garlic odor. In R.F. the coating volatilizes and colors the flame blue.

Colorado localities: near Leadville; reported from Boulder County.

Uses: In the oxide form (As_2O_3) it is used in dyeing and calico-printing; in the manufacture of various paints and paper-colorings; in preserving biological specimens, particularly skins. This and other salts of arsenic are used in medicine and for poisons.

NOTE.—The arsenic of commerce is derived largely from arsenopyrite.

ORPIMENT: Arsenic trisulphide, As_2S_3; arsenic 61 per cent.

Color: lemon-yellow to orange-yellow.

Luster: pearly on cleavage surface, resinous elsewhere.

Diaphaneity: subtransparent to nearly opaque.

Crystallization: monoclinic; crystals small and rarely distinct.

Cleavage: pinacoidal perfect; cleavage faces striated.

Fracture: cleavage plates flexible, inelastic.

Tenacity: sectile.

Hardness: 1.5—2.

Streak: pale lemon-yellow.

Specific gravity: 3.4—3.5.

Occurrence: commonly in foliated or columnar masses; sometimes with kidney-shaped surfaces. Deposited about volcanic or solfataric vents and hot springs. In clay beneath a lava flow in Iron County, Utah.

Associations: ores of silver and lead.

Tests: In closed tubes fuses, volatilizes, and gives a dark yellow sublimate. Dissolves in aqua regia and caustic alkalies. On charcoal burns with a blue flame, giving arsenic and sulphurous odors. Easily recognized by its fine color, beautiful luster, easy cleavage and flexible plates.

Uses: dyeing, and in preparation of a paste for removing hair from skins, and to a limited extent as a pigment.

ALLEMONTITE: Arsenical antimony, $SbAs_3$; arsenic 65.2 per cent, antimony 34.8 per cent; is a tin-white to reddish-gray mineral of brilliant to dull metallic luster, often tarnishing to brown or black. B.B. gives out fumes of arsenic and antimony, forms a metallic globule which burns and forms coating of antimony trioxide on the coal. It is associated with sphalerite, antimony, siderite, etc.

CLAUDITITE is arsenic trioxide, As_2O_3, in thin, platy and tabular monoclinic crystals. It is colorless to white, transparent to translucent; has a perfect cleavage, a fibrous fracture, a hardness of 2.5, and a specific gravity of 3.85. The tests are like those of arsenolite.

ARSENOLITE is native arsenic trioxide, As_2O_3; arsenic 75.8 per cent; occurring in crusts, botryoidal and stalactite masses more or less compact, but generally composed of fibrous, needle-like crystals. It also occurs in octahedral crystals and earthy masses. It is a white to yellowish or reddish mineral, having a vitreous or silky luster, white or pale-yellow streak, a specific gravity of 3.7, and a sweetish, astringent taste. It varies from transparent to opaque. *Tests*: In closed tube sublimes, condensing on upper part of tube in minute octahedrons. B.B. on coal volatilizes, giving out white fumes, an arsenical odor (onion or garlic), and forming a white coating. Weakly soluble in hot water. *Occurs*: in upper workings of mines producing arsenical ores of any kind.

ARSENIC-BEARING MINERALS DESCRIBED UNDER OTHER METALS: Annabergite, Mimetite, Smaltite, Löllingite, Niccolite, Arsenopyrite, Enargite, Tennantite, Proustite.

ANTIMONY AND ANTIMONY MINERALS

USES: Metallic antimony is used chiefly in alloys with other metals. Type-metal is an alloy of lead, antimony and bismuth. Britannia metal contains antimony, tin, zinc and copper, but lead, nickel and zinc are generally present. It is also used for coffin trimmings, linings for acid tanks, toys, clock-cases, and other purposes where a fairly hard metal is to be gilded. The uses of antimony salts may be grouped as follows: (a) medicine—the arsenate, the arsenite, the trichloride, the iodide, the trioxide, the trisulphide, the pentasulphide, the tartrate; (b) surfacing for iron, enamel, etc.—the trichloride; (c) coloring glass, rubber, porcelain, and as mordants—the antimonate, the sulphide, the chromate, some of the oxides, the fluoride, the oxalate, and the tartrate; (d) pigment—the trioxide is used in place of white lead; (e) fireworks, matches, etc.—the trisulphide; (f) chemical uses as a reducing agent and detector—the trioxide.

ANTIMONY MINERALS IMPORTANT AS ORES

ANTIMONY, NATIVE ANTIMONY: Metallic antimony, sometimes containing silver, arsenic or iron.

Color: tin-white.

Luster: metallic, darkening on exposure.

Diaphaneity: opaque.
Crystallization: hexagonal-rhombohedral; crystals rare.
Cleavage: one perfect, others distinct.
Fracture: uneven.
Tenacity: brittle.
Hardness: 3—3.5.
Streak: tin-white.
Specific gravity: 6.65—6.72.
Occurrence: usually massive granular in thin plates or crusts, cleavable and radiating subfibrous.
Tests: Fuses easily, giving flame pale-green color, and yields dense white fumes which tend to form crusts of prismatic crystals of white antimony trioxide over surface.
Economic: ore of antimony, but rarely important.

STIBNITE, ANTIMONITE, ANTIMONY GLANCE, GRAY ANTIMONY: Antimony trisulphide, Sb_2S_3; antimony 71.4 per cent.
Color: lead-gray to steel-gray; tarnishes readily.
Luster: metallic, highly splendent on fresh surfaces.
Diaphaneity: opaque.
Crystallization: orthorhombic; prismatic with vertical striæ or grooves, often curved or twisted, in aggregates and radiating groups.
Cleavage: one perfect.
Fracture: subconchoidal, small.
Tenacity: slightly sectile.
Hardness: 2.
Streak: lead-gray.
Specific gravity: 4.52—4.62.
Occurrence: as an ore, mainly massive granular, often showing radiation and cleavage.
Associations: quartz, sphalerite, galena, cinnabar, barite, sometimes native gold and other antimony minerals.
Rocks: usually granite or gneiss
Tests: Fuses very easily, giving flame greenish-blue color. In open tube sulphur and antimony fumes form non-volatile white sublimate. Soluble in hydrochloric acid. Decomposed by nitric acid, with separation of white antimony pentoxide.
Colorado: many places in the mining camps, but rarely in commercial quantity. Common in lead ores.
Economic: chief ore of antimony.

ANTIMONY MINERALS OF LESS IMPORTANCE

VALENTINITE, antimony trioxide, Sb_2O_3; antimony 83.3 per cent. *Color*: snow-white to gray, and occasionally brown and red. *Luster*: silky to adamantine to pearly. *Diaphaneity*: translucent. *Crystallization*: fan-shaped or star-shaped groups of slender or tabular crystals; also in columnar, lamellar and granular masses, as the result of alteration of antimony-bearing minerals. *Cleavage*: two perfect. *Hardness*: 2.5—3. *Streak*: white. *Specific gravity*: 5.57. *Tests*: same as for senarmonite.

SENARMONITE, antimony trioxide, Sb_2O_3; antimony 83.3 per cent. *Color*: colorless to grayish. *Luster*: resinous to weakly adamantine. *Diaphaneity*: transparent to translucent. *Crystallization*: isometric, octahedrons; also granular massive; in crusts, as a result of oxidation of ores of antimony, and ores containing antimony. *Cleavage*: only in traces. *Fracture*: uneven. *Hardness*: 2—2.5. *Streak*: white. *Specific gravity*: 5.2—5.3. *Tests*: In closed tube fuses and partially sublimates. B.B. fuses easily, coating coal white. The coating colors the reducing flame greenish-blue. Soluble in hydrochloric acid.

STIBICONITE, antimony ochre, probably $Sb_2O_4.H_2O$; antimony 74.5 per cent. A pale-yellowish to reddish-white mineral of pearly to earthy luster, having a hardness of 4.5—5, a specific gravity of 5.1—5.8, and occurring massive, compact and as powder, and in crusts. *Tests*: In closed tube yields water; on charcoal flies to pieces; fuses with difficulty to gray slag, giving white coating.

CERVANTITE, antimonous oxide, Sb_2O_4; antimony 78.9 per cent. A yellow to white or reddish-white mineral of variable luster—pearly, greasy and earthy—a white to yellowish streak, a hardness of 4—5, and a specific gravity of 4.08. Occurs in needle-like crystals, sometimes forming crusts; also massive and in powder. B.B. infusible; soluble in hydrochloric acid.

KERMESITE, antimony oxysulphide, Sb_2S_2O, or $2Sb_2S_3.Sb_2O_3$; antimony 75 per cent. Occurs generally in tufts of cherry-red, needle-like crystals of adamantine to metallic luster, feebly translucent. Gives ordinary antimony reactions.

ANTIMONY-BEARING MINERALS DESCRIBED ELSEWHERE: Tetrahedrite, Pyrargyrite, Zinkenite, Jamesonite, Bournonite, Stephanite.

BISMUTH AND BISMUTH MINERALS

USES: The metal is used in making solders and alloys of low fusion temperatures, used for safety plugs in boilers, and fire plugs in automatic sprinklers. It is also used in making electric fuses, and in certain kinds of optical glass. The salts are used in toilet powders and in medicines. Bismuth chromate (yellow) and the oxychloride (white) are used in paint. Other salts are used as chemical reagents.

ORES OF BISMUTH

BISMUTH, NATIVE BISMUTH: Metallic bismuth, commonly with traces of arsenic, sulphur, tellurium, etc.

Color: reddish silver-white; tarnishes.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: hexagonal; rhombohedral; usually in branching forms, rarely in distinct crystals.

Cleavage: one perfect.

Fracture: rather even.

Tenacity: sectile, brittle, but slightly malleable when heated.

Hardness: 2—2.5.

Streak: silver-white.

Specific gravity: 9.7—9.83.

Occurrence: mostly foliated or granular, in veins in gneiss, schist, clay, slate.

Associations: ores of silver, lead, zinc, cobalt, molybdenum and tungsten.

Tests: On charcoal fuses and volatilizes, giving an orange-yellow coating which becomes lemon-yellow when cool. Soluble in nitric acid; water added to solution causes white precipitate. On plaster slab with flux consisting of 2 parts sulphur, 1 part potassic iodide, and 1 part potassic bisulphate, gives a chocolate-brown and red coating, changed by ammonia fumes to red and orange.

Colorado: French Gulch, Summit County, Las Animas Mine.

BISMUTHINITE, BISMUTH GLANCE: Bismuth trisulphide, Bi_2S_3; bismuth 81.2 per cent.

Color: lead-gray to tin-white, with yellow tarnish.

Luster: metallic.

Diaphaneity: opaque.

Crystallization: orthorhombic; rarely in needle-like crystals.
Cleavage: one perfect.
Fracture: uneven.
Tenacity: slightly sectile.
Hardness: 2.
Streak: lead-gray to tin-white.
Specific gravity: 6.4—6.5.
Occurrence: usually massive, foliated or fibrous.
Tests: Fuses easily with spurting, yielding some sulphur fumes and white and yellow coatings on charcoal. On plaster slab with sulphur 2 parts, potassic iodide 1 part, potassic bisulphate 1 part, yields bright scarlet coat, with chocolate and reddish borders. Ammonia fumes turn the brown red.
Colorado: Leadville and elsewhere.

BISMITE, BISMUTH OCHRE: Bismuth trioxide, Bi_2O_3; bismuth 89.6 per cent. *Color*: greenish-yellow, to yellow, to grayish-white. *Luster*: adamantine to dull, earthy. *Diaphaneity*: The fresh mineral is translucent. *Crystallization*: amorphous, most commonly in earthy powder, but also massive and foliated. *Fracture*: weakly conchoidal, crumbling. *Streak*: earthy-gray to colorless. *Specific gravity*: 4.36. *Tests*: In closed tube generally yields water. B.B. on coal fuses, yielding bismuth, which on continued heating in oxidizing flame is volatilized, forming yellow oxide coating. Soluble in nitric acid.

BISMUTITE: A basic carbonate of bismuth, perhaps $Bi_2O_3.CO_2.H_2O$; with bismuth trioxide, Bi_2O_3, 88 to 90 per cent.
Color: white, to grayish-yellow, to yellow and various shades of green.
Luster: vitreous to dull by exposure; center of a mass may be vitreous while surface is earthy.
Diaphaneity: weakly translucent to opaque.
Crystallization: amorphous, in crusts or earthy and powdery over the surface of other ores of bismuth and other minerals containing bismuth.
Hardness: 4—4.5.
Streak: greenish-gray to colorless.
Specific gravity: 6.86—6.9.
Tests: In closed tube flies to pieces, yields water. B.B. fuses easily, coating the coal with yellow oxide of bismuth

Effervesces weakly in nitric acid, and with hydrochloric forms a deep-yellow solution.

Colorado localities: a part of the bismuth ore of Leadville is probably a mixture of bismutite and bismite in earthy form. It has been found on Mount Antero and is reported from mines in Boulder County and from the La Plata Mountains.

BISMUTH MINERALS OF LESS IMPORTANCE

TETRADYMITE consists of bismuth and tellurium, generally with traces of sulphur, and sometimes selenium. It is a pale steel-gray mineral of brilliant metallic luster, occurring in small rhombohedral crystals, and bladed forms and foliated to granular masses. It has a perfect cleavage, a hardness of 1.5—2, and a specific gravity of 7.2—7.6. It occurs in the Red Cloud mine, Boulder County, and is reported from others in the same county. It gives the usual reactions for bismuth and tellurium.

CUPROBISMUTHITE, sulphobismuthite of copper and silver, occurs in groups of dark bluish-black, slender, prismatic crystals, and compact masses, in the Missouri mine, Park County. The composition is probably $3Cu_2S.4Bi_2S_3$; bismuth 65.9 per cent, with silver and gold probably replacing part of the copper.

BEEGERITE is a sulphobismuthite of lead; bismuth 21.4 per cent, lead 63.8 per cent; occurring in granular masses of small size, and in indistinct crystals of gray color and bright metallic luster, in several mines in Park and Ouray Counties.

BISMUTH-BEARING MINERALS DESCRIBED ELSEWHERE: Cosalite, Aikinite.

TELLURIUM AND TELLURIUM MINERALS

USES: A limited amount of tellurium is used in glass manufacture. Blue, brown and red colors are produced. An alloy consisting of 50 to 85 parts of aluminum, 49 down to 14 parts of zinc, and one-fourth to one part of tellurium, is claimed to be superior to aluminum in tensile and torsional strength.

Experiments with tellurium in electrical apparatus suggest another field of usefulness.

TELLURIUM MINERALS

TELLURIUM, native tellurium, Te. It is a tin-white mineral of metallic luster and tin-white streak, occurring in minute hexagonal crystals and massive, columnar and fine granular forms, having a hardness of 2—2.5, and a specific gravity of 6.1—6.3. *Tests*: In open tube fuses readily, giving white sublimate of tellurium dioxide, which may be fused to colorless drops. On charcoal volatilizes, tingeing flame green. The powdered mineral gives characteristic reddish-violet solution with strong sulphuric acid.

Colorado: Native tellurium is found in considerable quantity in Boulder County mines, especially in the Central district about Sunshine; in the Bonanza district, Saguache County; and Vulcan in Gunnison County.

TELLURITE, tellurium dioxide, TeO_2, is a soft white or yellowish-white mineral of adamantine luster and perfect cleavage, occurring in prismatic, orthorhombic crystals and small spherical masses in several Cripple Creek mines.

EMMONSITE is probably a hydrated ferric tellurite. A clear, yellow-green mineral occurring in cleavage scales of rhombic outline. *Hardness*: 5. A mineral resembling emmonsite occurs in a number of Cripple Creek mines.

DURDENITE is a hydrous ferric telluride, $Fe_2O_3.3TeO_2.4H_2O$; tellurium dioxide, TeO_2, 67.1 per cent. A greenish-yellow, translucent to nearly opaque, friable mineral of vitreous to dull luster, and a hardness of 2—2.5, occurring massive, in mammillary forms, and disseminated grains, associated with native tellurium.

FERROTELLURITE, possibly $FeTeO_4$, is a greenish-yellow mineral occurring in delicate tufts of minute prismatic crystals on quartz, associated with native tellurium in the Keystone mine, Magnolia, Colorado. The iron may have come from a deposit on the surface of the mineral, and the real composition may be tellurous oxide.

MAGNOLITE, possibly Hg_2TeO_4, is a white, silky mineral occurring in tufts of needle-like crystals, probably from the decomposition of Coloradoite, found in the Keystone mine, Magnolia.

TELLURIUM MINERALS DESCRIBED ELSEWHERE: Empressite, Sylvanite, Calaverite, Krennerite, Nagyagite, Hessite, Petzite, Altaite, Coloradoite, Rickardite, Tetradymite.

TELLURIUM MINERALS NOT DESCRIBED: Melonite. Selen-tellurium, Montanite.

MERCURY, QUICKSILVER, AND ITS ORES

USES: The chief use of metallic mercury is in the extraction of gold and silver by the amalgamation process. The mercury unites with the silver or gold, forming amalgams, from which the mercury is driven by heat, leaving the silver or gold behind. A small amount of mercury is used in barometers and thermometers, and in various laboratory processes in chemistry. An amalgam of tin and mercury is used for silvering mirrors. Salts of mercury, chiefly calomel, mercurous chloride, Hg_2Cl_2, are used in medical science. Cinnabar, or an artificial sulphide, is used as a pigment—vermilion. Other mercury salts are used in pigments.

MERCURY MINERALS IMPORTANT AS ORES

CINNABAR: Mercuric sulphide, HgS; mercury (quicksilver), 86.2 per cent.

Color: Cochineal-red, scarlet, reddish-brown to almost black.

Luster: adamantine, sometimes inclining to metallic; also dull.

Diaphaneity: transparent to opaque.

Crystallization: hexagonal; rhombohedral, or thick tabular and slender prisms.

Cleavage: one perfect.

Fracture: subconchoidal.

Tenacity: brittle, sometimes friable.

Hardness: 2—2.5.

Streaks: scarlet.

Specific gravity: 8—8.2.

Occurrence: veins in slate and shale, as incrustations, granular masses, etc.; also about solfataras and hot springs.

Associations: pyrite, marcasite, sulphides of copper, stibnite, realgar, gold, calcite, quartz, barite, fluorite and bituminous minerals; slates, shales, porphyries and granites.

Tests: Heated in closed tube forms black sulphide of mercury; if soda is added, gives metallic mercury. In open tube slow heat gives metallic globules. B.B. on charcoal pure mineral volatilizes.

Colorado: various points in Boulder, Clear Creek and other counties, but not in commercial amount.

Economic: principal ore of mercury.

MERCURY, QUICKSILVER: Native mercury, Hg, with occasionally a little silver. It is a tin-white liquid metal of very brilliant metallic luster, and a specific gravity of 13.59. It occurs native, mostly in liquid globules scattered through the gangue, but sometimes in cavities in quantities large enough to be dipped up. Mercury occurs in both igneous and sedimentary rocks, but the commonest gangue seems to be clay shales and schists, in regions of great crustal disturbance. Found sparingly in tellurium-bearing mines of Boulder County. *Tests*: B.B. readily volatilizes, forming grayish-white fumes. Readily soluble in nitric acid.

MERCURY MINERALS OF LESS IMPORTANCE AS ORES

METACINNABARITE is a mercuric sulphide, HgS, like cinnabar, but crystallizing in the isometric system. *Color*: grayish-black. *Luster*: metallic. *Diaphaneity*: opaque. *Crystallization*: isometric, tetrahedrons; also massive and amorphous. *Fracture*: subconchoidal to uneven, brittle. *Hardness*: 3. *Specific gravity*: 7.7—7.8. *Occurrence*: associations, etc., same as cinnabar. *Tests*: same as for cinnabar.

COLORADOITE, MERCURIC TELLURIDE: HgTe; mercury 61.5 per cent, tellurium 38.5 per cent. *Color*: iron-black to grayish-black. *Luster*: metallic. *Crystallization*: massive, granular. *Cleavage*: none. *Fracture*: uneven to subconchoidal. *Hardness*: 2.5—3. *Specific gravity*: 8.7 and higher. *Occurs*: in Colorado at Keystone, Mountain Lion and Smuggler mines, Boulder County, with quartz, gold, native tellurium and sylvanite. *Tests*: In the tube fuses and yields a mirror of metallic mercury, and drops of tellurium dioxide, and near the mineral metallic tellurium. Soluble in nitric acid.

CALOMEL, HORN QUICKSILVER: Mercurous chloride, Hg_2Cl_2; mercury 84.9 per cent. *Color*: white, gray, yellowish and brown. *Luster*: adamantine. *Diaphaneity*: translucent to nearly opaque. *Crystallization*: tetragonal, tabular and prismatic crystals. *Cleavage*: one fair. *Fracture*: conchoidal. *Tenacity*: sectile. *Hardness*: 1—2. *Streak*: pale yellowish. *Specific gravity*: 6:48. *Occurrence*: generally associated with cinnabar, in shales, schists and less commonly igneous rocks. *Tests*: In closed tube volatilizes, and condenses as white sublimate on cooler part of tube; with soda in the tube gives a ring or mirror of metallic mercury. Soluble in aqua regia (mixture of nitric and hydrochloric acids).

AMALGAM is described under silver ores.

MERCURY MINERALS DESCRIBED ELSEWHERE: Onofrite, Tiemannite.

CADMIUM AND THE SOURCES OF CADMIUM

USES: The principal uses of metallic cadmium are in amalgams and alloys. Dental amalgam contains cadmium 26 per cent, and mercury 74 per cent. Cliché metal, for stereotyping plates, is improved in hardness and wear by the substitution of cadmium for bismuth. The alloy contains: lead 50, tin 27.5, and cadmium 22.5 per cent. Many low-fusion alloys containing cadmium are used as solders, fusion plugs, etc.

Salts of cadmium are used in glass- and porcelain-coloring, dyeing and calico-printing, photography, fireworks and dentistry.

The "ammonio-sulphate" is used in electroplating, both alone and with silver salts. The sulphide, cadmium yellow, is a very desirable yellow pigment.

The cadmium cell is used for measuring electromotive force. The cadmium spectrum is used for standardizing measures used as units of length.

SOURCES: The principal sources of the cadmium of commerce are the ores of zinc, and zinc-bearing lead ores. The cadmium is obtained: 1, as a by-product in the refining of zinc by distillation; 2, as a by-product from the bag-house fumes of smelters treating zinc-bearing lead ores, and, 3, from the residues, dross and zinc ashes resulting from the manufacture of zinc chloride.

It is placed on the market in the metallic and the sulphide forms. A very large part of the American production comes from Colorado lead-zinc ores.

GREENOCKITE, CADMIUM-BLENDE: Cadmium sulphide, CdS; cadmium 77.7 per cent.

Color: various shades of yellow from very pale to rather deep and bronzy.

Luster: adamantine to resinous and earthy.

Diaphaneity: nearly transparent.

Crystallization: hexagonal; (hemimorphic), crystals rare.

Cleavage: one fair.

Fracture: conchoidal. Brittle.

Hardness: 3—3.5.

Streak: orange-yellow to brownish-red.

Specific gravity: 4.9—5.

Occurrence: generally as a yellow powder over the surface of sphalerite and smithsonite, and occasionally other zinc minerals.

Associations: zinc minerals.

Tests: In closed tube turns carmine while hot, but fades on cooling. Infusible, but easily volatile in the reducing flame—inner blue flame—coating the coal with a brown coat and iridescent tarnish. Soluble in strong hydrochloric acid, yielding hydrogen sulphide.

MANY ZINC ORES contain appreciable amounts of cadmium and are the chief source of the metal.

MINERALS CONTAINING CERIUM, COLUMBIUM, (NIOBBIUM), DIDYMIUM, GLUCINUM, (BERYLLIUM), LANTHANUM, TANTALUM, THORIUM, YTTRIUM, ZIRCONIUM.

USES: Various metals and metallic oxides are now being used and tested in the manufacture of filaments for electric lamps and the mantles for incandescent gas lamps. These include the metals tantalum and cadmium and the oxides zirconia, thoria, yttria, and those of cerium, lanthanum and didymium. The mantles for incandescent gas lights are composed largely of thoria, ThO_2, with small quantities of the oxides of lanthanum and didymium. The thoria is obtained chiefly from MONAZITE. Cerium fluoride is used in the arc of the flaming arc lamp. Tantalum is drawn into a fine wire and used as a filament in the tantalum lamp. The "glower" of the Nernst electric lamp is made of a mixture of zirconia and yttria. Zirconium filaments are used to some extent. Most of the oxides of the rare earth metals are highly refractory, and it seems probable that important uses may be found for them.

Alloys of the cerium earth metals and iron with small percentages of other elements are used for producing fire in much the same way as flint and steel were used generations ago. These alloys when filed or scraped or struck lightly yield sparks which will ignite gases. These alloys are known under various trade names such as "misch metal alloys," "ferro-cerium alloy," "pyrophoric alloy." Those in common use contain mainly the cerium earth metals and iron. But antimony or bismuth is present in some, copper up to 5 per cent in some, zinc in varying percentage in others, and silicon (probably as an impurity) in most of them. Other metals such as mercury, platinum and magnesium are used, and boron has been tried in these alloys.

The "misch metal" used in making these alloys contains besides cerium; lanthanum, didymium, neodymium, praesodymium and samarium. It comes from the residues of the monazite sands from which the thorium has been taken for the manufacture of gas mantles.

The chief minerals from which these metals and oxides are obtained are ZIRCON, MONAZITE, GADOLINITE and COLUMBITE-TANTALITE. Many other minerals contain them, but are not yet found in commercial quantities. Some of these are ALLANITE, THORITE, THORIANITE and SAMARSKITE. A fuller list may be found in *Mineral Resources,* U. S. Geological Survey for 1904.

OCCURRENCE: Many of the minerals of the rare earths, as well as others which find similar uses, occur in pegmatite dikes, granites and gneisses. They should be sought in the great areas of granite and gneiss in which are thousands of pegmatite dikes.

ALLANITE, ORTHITE: A complex silicate of calcium, iron, aluminum; certain of the cerium metals—cerium, didymium, lanthanum; and in smaller amounts those of the yttrium group, $4RO.3R_2O_3.6SiO_2.H_2O$; with $R = Ca$ and Fe, and $R_2 = Al$, Fe, Ca, Di, La, etc.

Color: brown to black.

Luster: submetallic, pitchy or resinous.

Diaphaneity: translucent to almost opaque.

Crystallization: monoclinic; in tabular, and long, slender to acicular prismatic crystals.

Cleavage: orthopinacoidal and basal rather poor.

Fracture: uneven to subconchoidal. Brittle.

Hardness: 5.5—6.

Streak: pale brown to brownish-black.

Specific gravity: 3.0—4.2.

Occurrence: in crystals and crystal grains, and massive, in certain granites, syenites and gneisses; and in smaller quantity in andesite, diorite and dacite. It also occurs in impure white limestones.

Associations: the minerals of granites, syenites, etc., and epidote, sanidine, sodalite, hornblende and magnetite.

Tests: Fuses at 2.5 to a dark, vesicular, magnetic glass. With soda or borax reacts for iron. Most varieties gelatinize with hydrochloric acid, but if previously ignited are not decomposed by acid.

Colorado localities: Devils Head, Douglas County; in several gneisses and granites near Boulder, where the crystals are flattish, tabular.

CERITE: A silicate of the metals of the cerium group with iron and calcium and water. Formula doubtful.

Color: dull adamantine to resinous.

Crystallization: orthorhombic; short prismatic. The mineral is generally massive and granular. It resembles a red granular variety of corundum.

Fracture: splintery.

Tenacity: brittle.

Hardness: 5.5; (corundum 9).

Streak: grayish white.

Specific gravity: 4.86—4.9.

Occurrence: in gneiss with hornblende, allanite, chalcopyrite.

Tests: In closed tube yields water. B.B. infusible alone; with borax in outer flame forms yellow globule which pales on cooling; in the inner flame gives weak iron reaction. With soda fuses to dark yellow slag. Gelatinizes with hydrochloric acid.

MONAZITE is an anhydrous phosphate of the rare earths cerium, lanthanum and didymium, with from 1 to 20 per cent of thoria, $(Ca, La, Di)PO_4$. The value of monazite depends upon the thoria present. *Color*: light-yellow, honey-yellow, reddish, brownish, yellowish-green, and almost colorless. *Luster*: vitreous to resinous. *Diaphaneity*: translucent to almost opaque. *Crystallization*: generally small monoclinic crystals, sometimes prismatic. The monazite of commerce is in rounded and subangular grains, some of which show crystal faces. *Cleavage*: one good, one distinct. *Fracture*: conchoidal to uneven, brittle. *Hardness*: 5—5.5. *Specific gravity*: 5—5.2. *Occurrence*: in various rocks, but chiefly granites, gneisses, and schists. The monazite of commerce is obtained chiefly from North Carolina, South Carolina and Brazil. The Carolina deposits are monazite placers, in which running waters have concentrated the monazite grains. *Associations*: garnets, magnetite and quartz are the commoner constituents of the gravels and sands. *Tests*: B.B. infusible, turns gray, and gives a greenish flame (phosphorus) when moistened with sulphuric acid. Slowly soluble in hydrochloric acid. It is generally radioactive on account of the small amount of uranium present—not the thorium.

Colorado: Found sparingly in the stream sands and gravels of the Front Range.

COLUMBITE-TANTALITE: Pure columbite, $FeO.Cb_2O_5$, and pure tantalite, $FeO.Ta_2O_5$, are rather rare, but a mineral containing both columbium and tantalum, $(Fe, Mn)(Cb, Ta)_2O_6$, in varying proportions is commoner. Columbite would contain 82.7 per cent of columbium pentoxide; and tantalite would yield 86.1 per cent of tantalum pentoxide.

Color: black, to iron-gray, to shades of brown; often iridescent.

Luster: submetallic to almost metallic.

Diaphaneity: opaque, rarely translucent.

Crystallization: orthorhombic; twins of heart shape, short prisms, and in groups of parallel crystals and massive.

Cleavage: one rather distinct and one poor, at right angles.

Fracture: subconchoidal to uneven. Brittle.

Hardness: 6.

Streak: dark red to black.

Specific gravity: 5.3—7.3.

Occurrence: mainly in granite and pegmatite. Massive tantalite occurs in Yancey County, North Carolina.

Associations: the minerals of pegmatite veins and granite, such as feldspars, tin ores, mica, spodumene, lepidolite, monazite, etc.

Tests: *Tantalite*: B.B. alone unaltered. With salt of phosphorus dissolves slowly to glassy bead, which cools from the oxidizing flame to pale yellow. With tin on charcoal becomes green. Fused with potassium hydroxide or potassium bisulphate, and boiled with tin or zinc, gives blue solution, which fades when diluted with water. *Columbite*: The blue color produced by same treatment is more lasting. Boiled with hydrochloric acid and zinc gives beautiful blue.

Economic: Tantalum is used in the filament of the tantalum lamp.

Colorado localities: on and in the microcline of Pikes Peak region, and along Turkey Creek in Jefferson County, and in large masses seven miles west of Canon City.

SAMARSKITE is essentially a columbate (niobate) and tantalate of iron and calcium with the cerium and yttrium metals, together with uranium oxide. The yttrium oxides vary from 6 to 15 per cent, and the cerium oxides from 2 to 6 per cent. Tantalum pentoxide, Ta_2O_5, and columbium pentoxide, Cb_2O_5, make up about 56 per cent. *Color*: velvet-black. *Luster*: vitreous to splendent and resinous. *Crystallization*: commonly massive or in flattened, imbedded grains; occasionally in prismatic crystals. *Cleavage*: one poor. *Fracture*: conchoidal, brittle. *Hardness*: 5—6. *Specific gravity*: 5.6—5.8. *Occurrence*: mainly in pegmatite dikes, and especially in the micaceous parts associated with columbite. *Colorado locality*: A closely related mineral is found in the granite debris of Devils Head Mountain, Douglas County. *Tests*: In closed tube flies to pieces, glows like gadolinite, cracks open, glows and turns black. B.B. fuses on thin edges to black glass. Decomposed on fusion with potassium bisulphate, yielding a yellow mass which, when treated with dilute hydrochloric acid, separates with tantalic acid, and on boiling with metallic zinc gives a fine blue color. The powdered mineral boiled in strong sulphuric acid yields blue color when metallic tin or zinc is added. *Economic*: See general statement on page 252.

NOHLITE and VIETINGHOFITE are varieties of Samarskite.

THORIANITE is a thorium-uranium oxide, containing about 7 per cent of thoria, ThO_2, and 12.5 per cent of uranium oxide, U_3O_8. It occurs in cubical, black crystals having a specific gravity of 9.3, and giving a black streak. It is associated with zircon, corundum, topaz, tin oxide, spinel, etc. It is highly radioactive and yields a larger amount of helium than any other known mineral. It should be looked for wherever topaz, zircon and monazite are found. The Pikes Peak region is suggested, and the uranium areas in western Colorado. *Economic*: source of thoria and radium.

THORITE: Anhydrous thorium silicate, $ThO_2.SiO_2$; thoria 81.5 per cent. The mineral is generally partially hydrated.

Color: orange, to yellow, to brown and black.

Luster: fresh surface vitreous to resinous and greasy.

Diaphaneity: transparent to nearly opaque.

Crystallization: tetragonal prisms terminated by pyramids; also massive and compact.

Cleavage: one distinct (prismatic).
Fracture: conchoidal, brittle.
Hardness: 4.5—5.
Streak: orange-yellow to brown.
Specific gravity: 5.19—5.4.
Tests: B.B. on charcoal, infusible; with borax forms a yellowish, pearly bead, fading on cooling, but if niter is added the orange color remains. In closed tube yields water. Powdered mineral decomposed by hydrochloric acid forming gelatinous mass. Does not gelatinize after ignition.
Economic: Thoria is used in the mantles for incandescent gas burners, and the demand is increasing. It should be looked for in the vicinity of Pikes Peak, and St. Peters Dome. Thorite is radioactive.

ORANGITE is a bright orange-yellow variety of thorite.

GADOLINITE, a basic orthosilicate of glucinum (beryllium), iron and yttrium, $2GlO.FeO.2Y_2O_3.2SiO_2$; glucina (beryllia), GlO, 10.0 per cent; yttrium oxide, Y_2O_3, 51.8 per cent. *Color*: black, greenish-black, brown. *Luster*: vitreous to greasy. *Diaphaneity*: transparent to translucent. *Crystallization*: rough, coarse monoclinic prisms terminated by pyramids; also in amorphous masses. *Cleavage*: none. *Fracture*: conchoidal, splintery, brittle. *Hardness*: 6.5—7. *Streak*: greenish-gray. *Specific gravity*: 4—4.5. *Occurrence*: pegmatite veins along with allanite and similar minerals containing cerium, glucinum, columbium, etc., in rounded masses or nodules inclosed by a reddish crust of altered material. *Associations*: allanite, yttrialite, nivenite, gummite, fluorite, molybdenite, thorogummite, etc., most of which are radioactive. *Colorado locality*: Devils Head Mountain, Douglas County. *Tests*: The glassy mineral heated B.B. gives momentary bright light, as if burning, swells, cracks open, and becomes grayish-green, but does not fuse. The normal crystals swell, branch and become white. With borax reacts for iron. Decomposed by hydrochloric acid, with separation of gelatinous silica. The amorphous mineral, when heated, evolves much light and becomes denser. It is commonly radioactive.

ZIRCON is described elsewhere.

TYSONITE AND BASTNÄSITE are cerium minerals occurring near Pike's Peak. PARISITE is a fluocarbonate of cerium. These are not sources of cerium.

CHARACTERISTIC REACTIONS OF THE MORE IMPORTANT ELEMENTS

(Symbols and atomic weights follow the names of the elements.)

ALUMINUM, Al, 27.

1. *Cobalt Nitrate*: Light colored, infusible aluminum minerals, finely powdered, moistened with cobalt nitrate solution and intensely heated on coal turn beautiful blue. Zinc silicates give the same color, but react for zinc.

2. *Precipitation by Ammonia*: Ammonia added to acid solutions containing aluminum, precipitates cloudy white aluminum hydroxide. To prove: Collect the precipitate on filter paper, wash with water, place part of it in a test tube and add potassium hydroxide. If it is aluminum hydroxide it readily dissolves. Test the remainder of the precipitate with cobalt nitrate. (See further under silicon, No. 3.)

ANTIMONY, Sb, 120.

1. *Coating on Gypsum*: Powdered antimony minerals mixed with three or four parts of bismuth flux, (1 part potassium iodide, 2 parts sulphur, 1 part potassium bisulphate), or moistened with hydriodic acid, and heated in the O.F. on a gypsum slab, yield a red coating, which disappears if exposed to strong ammonia fumes.

2. *Sublimate on Charcoal*: Many antimony minerals heated on coal, in the O.F., yield a dense, white, easily volatile coating near the mineral, becoming thinner and bluish farther away. The fumes have no characteristic odor, and the sublimate is easily driven about the coal by the blowpipe flame.

3. *Open Tube*: Metallic antimony and antimony sulphides powdered and heated in an open tube yield a heavy white sublimate along the under side of the tube, and possibly a ring near the mineral. The ring is easily driven along the tube by the blowpipe flame. The other deposit is not volatile, and is pale yellow white hot, but white when cold.

4. *Flame Color*: Antimony when volatilized by strongly heating a mineral in the R.F. colors the flame pale greenish.

Argon, A, 40.

ARSENIC, As, 75.

1. *Coating on Coal*: Metallic arsenic, arsenic sulphides, and the arsenides of other metals, heated on coal yield white fumes of onion or garlic odor and a white, crystalline coating of arsenic trioxide far from the mineral.

2. *Coating on Gypsum*: Powdered arsenic minerals mixed with bismuth flux, (See No. 1, under antimony.), or moistened with hydriodic acid and heated in the O.F. on a gypsum slab, yield a volatile orange-yellow coating.

3. *Open Tube*: Powdered arsenic minerals heated in an open tube form a ring of arsenic trioxide on the glass near the assay. The ring may be driven up the tube by the flame.

4. *Closed Tube*: Metallic arsenic and some arsenides heated in a closed tube yield a brilliant, black, metallic, arsenic mirror, which may appear gray near the assay.

5. *Flame Color*: Arsenic volatilized by strongly heating mineral in the R.F. gives a violet tinge to the flame.

BARIUM, Ba, 137.4.

1. *Flame Color*: Most barium minerals color the flame yellowish green. The color is sometimes intensified by moistening the powder with hydrochloric acid. Prove by other tests, as boron and phosphorus give green flames.

2. *Barium Sulphate Precipitate*: A few drops of dilute sulphuric acid added to solutions containing barium will precipitate white barium sulphate, which will give the flame test. Minerals insoluble in acids are powdered and fused with three parts soda and then dissolved in hydrochloric acid.

3. *Alkaline Reaction*: Some barium minerals, powdered and intensely heated, give a brown color on moist turmeric paper.

Beryllium, Be, 9.

BISMUTH, Bi, 208.

1. *Coating on Gypsum and Charcoal*: Powdered bismuth minerals mixed with bismuth flux or moistened with hydriodic acid and heated, in the O.F., on a gypsum slab give a chocolate-brown coating, changed to bright red by ammonia fumes. On charcoal the coating is yellow near the assay and bordered by bright red.

2. *Metallic Bismuth and Coating on Charcoal*: The powdered mineral heated with three volumes of soda on charcoal, yields a brittle globule of metallic bismuth, and a yellow coating bordered with white. Lead globules are malleable.

3. *White Precipitate in water*: If the mineral is soluble in hydrochloric acid, evaporate the solution to a few drops, and pour it into a test tube one-third full of water. A white precipitate is formed and may be tested as in No. 2.

BORON, B, 11.

1. *Flame Color*: The powder of many boron minerals colors the blowpipe flame yellowish green. Some must be mixed with three volumes of potassium bisulphate and 1 of fluorite and gently heated, to secure the green flame.

2. *Reddish brown Color on Turmeric Paper*: Turmeric paper moistened in a hydrochloric acid solution of a boron mineral, and dried on a test tube containing boiling water, is turned reddish brown, and the brown turns to inky black when the paper is moistened with ammonia. Insoluble minerals are first fused with soda.

Bromine, Br, 80.
Cadmium, Cd, 112.
Caesium, Cs, 133.

CALCIUM, Ca, 40.

1. *Precipitation of Calcium Sulphate*: A few drops of dilute sulphuric acid added to a solution containing calcium, will precipitate minute white crystals of calcium sulphate, readily dissolved by adding water and boiling. If the solution supposed to contain calcium is very dilute, concentrate it by boiling. If very acid, add a little ammonia before testing with sulphuric acid.

2. *Calcium Precipitated as Carbonate*: When ammonium carbonate is added to a boiling solution containing calcium, made strongly alkaline with ammonia, a fine white precipitate of calcium carbonate is formed.

3. *Calcium Oxalate Precipitate*: If ammonium oxalate is added to a hot alkaline or slightly acid solution containing calcium, a very fine white precipitate is formed. The solution must be acid if phosphorus, silica or boron is present.

4. *Alkaline Reaction on Turmeric Paper*: The powdered mineral after strongly heating gives an alkaline reaction on turmeric paper.

(See further under silicon, No. 3.)

CARBON, C, 12.

Carbonates: The powdered minerals treated with dilute acid, warmed if necessary, yield carbon dioxide with effervescence. By slightly tipping the test tube the carbon dioxide may be poured off, as formed, into another tube containing barium hydroxide. On shaking the tube barium carbonate is formed as a white precipitate.

Cerium, Ce, 140.

CHLORINE, Cl, 35.5.

1. *Chlorine Given Off:* Many powdered chlorides, heated with a little manganese dioxide, or pyrolusite, with several times their volume of acid potassium sulphate, give off chlorine, a pungent greenish gas which bleaches litmus paper held in the tube.

2. *Silver Chloride Precipitated:* When silver nitrate solution is added to a chloride solution in water or dilute nitric acid, it forms a white precipitate of silver chloride, which changes to violet when exposed to light.

3. *Flame Color with Copper Oxide:* Moisten a mixture of the powdered mineral with sulphuric acid, and heat slowly until red. The flame is azure-blue.

CHROMIUM, Cr, 52.

1. *Borax Bead Colors:* Form a bead by burning borax in a loop of platinum wire. With the hot bead take up a little powdered mineral and heat in the O.F. The bead is yellow while hot, yellowish green when cold. In the R.F. it is green both hot and cold. With more mineral in the O.F., the colors are red when hot, yellowish green when cold.

2. *Salt of Phosphorus Bead Colors:* In O.F. the bead is dirty green when hot, clear green when cold. In the R.F. the colors are paler. Vanadium differs in giving a yellow bead in the O.F.

COBALT, Co, 59.

1. *Borax and Salt of Phosphorus Bead Colors:* The beads are fine blue, hot and cold, in both flames. If copper or nickel interferes, place the bead on coal with a granule of tin in a strong R.F. The copper or nickel will be reduced to metal and the flux will become blue.

COPPER, Cu, 64.

1. *Flame Color*: All common copper minerals give an emerald green flame. Moisten the mineral powder with hydrochloric acid or add a grain of salt. The flame is azure-blue.

2. *Blue Solution with Ammonia*: When ammonia is added in excess to a nitric acid or hydrochloric acid solution containing copper it gives a deep blue color. Nickel gives a paler blue.

3. *Metallic Copper*: Most copper ores after roasting yield a copper globule when fused on coal with several times their volume of a flux made of 1 part soda and 1 part borax.

Erbium, Er, 166.

FLUORINE, F, 19.

1. *Etching Glass*: Make a paste by moistening the powdered mineral with concentrated sulphuric acid. Coat a glass with paraffin and make a few scratches in the paraffin exposing the glass. Spread the paste over the paraffin and let it stand a few minutes. Clean the glass and observe the etching.

Gallium, Ga, 70.
Germanium, Ge, 72.

GOLD, Au, 197.2.

1. *Solubility*: Gold is insoluble in any single acid, while all minerals of similar color are soluble in one or another of the common acids.

2. *Malleability*: Even very small grains of gold may be hammered out without forming a powder.

3. *Specific Gravity*: Much higher than that of any mineral likely to be mistaken for it. It ranges from 15 to 19.3.

4. *Sectile*: Gold will yield chips or shavings, not powder or grains, when cut with a knife.

5. *Free Gold*: Much gold occurs in metallic grains. An ore containing free gold in profitable amount may be crushed to a fine powder and the rock dust washed away with care, leaving only grains of metallic minerals and gold. Practice will soon enable one to separate the gold grains, ''colors,'' from the much lighter mineral grains. Pyrite grains may be mistaken for gold, but they will crush to a powder under the knife blade.

A few drops of mercury may be placed in the pan and the mass shaken for some time. The mercury will collect the gold, and the remaining mineral matter is easily removed. Place the mercury in a cavity on charcoal and heat gently with a blowpipe. The mercury is driven off in vapor, and the gold may be formed into a globule by fusing with borax or soda. Do not breathe the mercury fumes.

6. *Tellurides*: Much gold occurs in the form of tellurides which may be detected as described under tellurium. Persistent heating with the blowpipe will drive off the tellurium as white fumes and leave a globule of metallic gold.

Helium, He, 4.
Hydrogen, H, 1.
Indium, In, 114.
Iodine, I, 126.
Iridium, Ir, 193.

IRON, Fe, 56.

See "Tests" under: *Magnetite, Hematite, Limonite, Siderite,* etc.

1. *Magnetism:* Magnetite, specular hematite, ilmenite, and pyrrhotite respond to the magnet—the last three very weakly. Hematite, limonite, goethite, turgite, siderite, pyrite, pyrrhotite and other iron minerals may be made magnetic by strongly heating them in R.F. on charcoal, with or without soda.

2. *Borax Bead Colors*: With a small amount of iron the bead in the O.F. is yellow when hot, and nearly colorless when cold; with more iron it is brownish-red when hot, yellow when cold. In the R.F. with little iron, the bead is pale green when hot, colorless when cold. With more iron it is bottle-green when hot, and pale green when cold. Roast sulphides and arsenides before making bead tests.

3. *Precipitate of Iron Hydroxide*: Ammonia added to a dilute solution in nitric acid or hydrochloric acid in which a few drops of nitric acid have been boiled, gives a brownish-red precipitate. Without the nitric acid the hydrochloric acid solution gives a greenish precipitate, which turns brown.

4. *Ferrous and Ferric Iron*:

Potassium ferr*i*cyanide added to a *ferrous* solution gives a dark blue precipitate; added to a *ferric* solution it merely deepens the color.

Potassium ferr*o*cyanide added to a *ferrous* solution gives a pale bluish white precipitate which quickly turns blue; added to *ferric* solutions it gives a dark blue precipitate.

Potassium sulphocyanide added to *ferric* solutions gives a dark red color. (See further under silicon, No. 3.)

Krypton, Kr, 82.

Lanthanum, La, 138.

LEAD, Pb, 207.

1. *Coating on Gypsum*: The powdered mineral heated with three or four times its volume of bismuth flux on a gypsum slab gives a coating varying from fine yellow near the assay to greenish yellow on the borders.

2. *Metallic Lead and Coating on Charcoal*: A mixture of 1 part powdered mineral, 1 part charcoal dust and 3 parts soda, fused in the R.F. will give globules of metallic lead, and a coating of lead oxide, yellow near the assay and paling to bluish white on the borders.

3. *Precipitates*: Sulphuric or hydrochloric acid added to a nitric acid solution gives a white precipitate, which may be tested by 1, 2 or 4.

4. The powdered mineral heated on charcoal with three or four times its volume of a mixture of potassium iodide and sulphur in equal parts gives a beautiful coating of red, yellow and green bordered with white.

LITHIUM, Li, 7.

1. *Flame Color*: Mix the powdered mineral with the same volume of powdered gypsum and hold it in the flame on a platinum wire. The flame is deep crimson—darker than the strontium and calcium flames.

MAGNESIUM, Mg, 24.

1. *Color with Cobalt Nitrate*: Several light colored magnesium minerals when moistened with cobalt solution and strongly heated turn pink.

2. *Reaction with Turmeric Paper*: Some magnesium minerals after strong heating give a brownish color to moistened turmeric paper.

3. *Precipitation from Solution*: Boil a dilute hydrochloric acid solution with a drop or two of nitric acid, add excess of ammonia, filter, add ammonia and ammonium oxalate, filter if necessary, add ammonium sulphide and filter if necessary. Add sodium phosphate. A crystalline precipitate shows the presence of magnesium.

(See further under silicon, No. 3.)

MANGANESE, Mn, 55.

1. *Sodium Carbonate Bead Colors*: Fuse soda in a loop of platinum wire and take up a small amount of the mineral. In the O.F. the bead is green when hot, and blue-green when cold. In the R.F. the bead becomes almost white. The test may be made on a piece of platinum foil. A little potassium nitrate frequently improves the reaction.

2. *Borax Bead Colors*: In the O.F. the bead is opaque while hot, and reddish violet when cold. In the R.F. the bead becomes colorless. A very small amount of the mineral is needed.

3. *Salt of Phosphorus Bead Colors*: The colors are similar to those of the borax bead, but less distinctive.

4. *Evolution of Chlorine*: When the higher oxides of manganese are dissolved in hydrochloric acid, chlorine, a pungent, greenish gas, is given off. Test the chlorine by its bleaching effect on moistened calico.

MERCURY, Hg, 200.

1. *Separation of Metallic Mercury*: Mix 1 part of the powdered mineral with 4 parts of dried soda, place in a closed tube, add a covering of dry soda and heat gently. A gray coating of minute globules, or a darker coating of larger globules will form on the tube. For amalgams the soda is not needed.

Most mercury compounds yield a dark mirror-like ring when heated alone in a closed tube.

2. *Precipitation of Metallic Mercury on Copper*: A piece of clean copper dipped into a solution containing mercury becomes coated with silvery white metallic mercury.

MOLYBDENUM, Mo, 96.

1. *Deposit in Open Tube*: Finely divided molybdenite heated intensely in an open tube gives a yellow deposit of molybdenum trioxide on the walls of the tube, and frequently delicate crystals.

2. *Flame Color*: If molybdenite is heated at the tip of the blue cone of the flame, a pale yellowish-green color appears.

3. *Color of Solution*: Mix 1 part powdered mineral, (roasted, if a sulphide), 3 parts soda and 3 parts niter, fuse a portion on platinum foil or make several beads on platinum wire, dissolve the fused mass in boiling water, pour off the clear liquid, add to it a few drops of hydrochloric acid and a small piece of copper, heat slightly. The solution becomes a fine blue. The blue disappears on strong heating, but reappears on cooling.

4. *Color on Gypsum*: Moisten the powdered mineral with hydriodic acid, or mix it with bismuth flux, on gypsum and heat strongly in the O.F. A deep ultramarine blue appears near the assay.

5. Any molybdenum minerals except molybdenite may be tested by heating a small piece, half the size of a grain of wheat, in a porcelain crucible with a drop of sulphuric acid until the fumes have nearly ceased. When the crucible has cooled it will have a beautiful deep blue coating. Molybdenite may be tested in this way by first oxidizing the powdered *mineral* in the blowpipe flame or boiling it to dryness in nitric acid.

Neodymium, Nd, 144.

NICKEL, Ni, 59.

1. *Borax Bead Color*: Add a very small grain of the well roasted mineral to a borax bead. In the O.F. it is violet while hot, reddish-brown when cold. In the R.F. long heating makes the bead opaque. The bead heated on coal with a grain of tin becomes colorless. Iron, cobalt and copper in the mineral will obscure the reaction for nickel. These may be treated as follows: Roast the powdered mineral into a globule one-eighth inch in diameter, place it on coal with borax and heat in the O.F. When the borax becomes colored by iron, (See No. 2 under iron,), remove it and repeat with more borax. After all iron is removed, cobalt will give the borax a blue color. Continue adding and removing borax until nickel colors it reddish brown.

Copper may be detected by treating the bead with salt of phosphorus in the O.F. Nickel alone gives a pure yellow color, while nickel and copper give a greenish yellow, or, if copper is abundant, a green. To confirm the copper, heat the bead on coal with tin in the R.F. It becomes red and turbid or opaque.

2. *Color of Precipitate*: Nickel minerals dissolved in nitric acid give apple green solutions. Ammonia gives them a pale blue color. (Copper gives a deep blue when ammonia is added.)

Niobium, Nb, 94.
Nitrogen, N, 14.
Osmium, Os, 191.
Oxygen, O, 16.
Palladium, Pd, 106.

PHOSPHORUS, P, 31.

1. *Flame Color*: The powdered mineral gives a pale bluish green color to the flame. Some minerals must be moistened with sulphuric acid before the color is shown.

2. *Yellow Precipitate with Ammonium Molybdate*: The mineral, (fused with soda if necessary), is dissolved in nitric acid, and a few drops of the solution are added to a solution of ammonium molybdate. A yellow precipitate forms in a few minutes.

PLATINUM, Pt, 195.

1. *Platinum* is a gray-white metallic mineral, infusible, malleable, insoluble in any single acid, but forming a reddish yellow solution with aqua regia, a mixture of nitric and hydrochloric acids.

Satisfactory and trustworthy chemical tests for platinum are hard to make outside a well-equipped laboratory.

2. The following method for the detection of platinum is given by A. Lynn de Spain in the Mining American for October 28, 1916, page 7:

"Dissolve in a casserole 5 grs. of the platinum ore by means of aqua regia (HCl 3 parts; NHO_3 1 part), boil gently for a few minutes. When the process of decomposition of ore is well under way, place the casserole on water bath and evaporate to dryness, heating the residue gently until every trace of HNO_3 is expelled. Take up with water and filter. Add to the clear solution a few drops of KI solution, when, if platinum is present, the sparingly soluble yellow chloroplatinate (K_2PtCl_6) is formed.

"The reaction takes place because of the interaction of chloroplatinic acid (H_2PtCl_6) with the KI, or other soluble potassium salt. Ammonium salts may be used in place of the salts of potassium."

3. Penfield recommends the following method: "Fuse the metal in a cavity on charcoal with some test-lead, using borax, if necessary, to take up impurities. The metallic globule, freed from slag by hammering, is then treated with dilute nitric acid ($1HNO_3$: $2H_2O$), which dissolves everything but the platinum metals and gold, and these are then collected upon a filter-paper, washed, and ignited. The finely divided platinum thus obtained dissolves readily in aqua regia, giving a reddish-yellow solution containing hydrochlorplatinic acid, H_2PtCl_6, which should be evaporated nearly to dryness, at a moderate heat, treated with hydrochloric acid, and again evaporated. It should be finally taken up with a little wa-

ter, filtered, if necessary, and added to a concentrated solution of ammonium chloride, when a yellow precipitate of ammonium platinic chloride $(NH_4)_2PtCl_6$, will be thrown down. The precipitate, if collected upon a filter, washed with alcohol, and ignited, yields a gray platinum sponge, containing often some other metals of the platinum group. Gold, if present, will be in the filtrate.''

Iridium and *Iridosmine* are insoluble in aqua regia.

POTASSIUM, K, 39.

1. *Flame Color*: Many potassium minerals when powdered give the flame a rich, pale violet color. Silicates must be powdered and mixed with an equal volume of powdered gypsum and applied to the flame on moistened platinum wire. The yellow soda flame, which may obscure the potassium flame, is cut out by blue glass.

2. *Alkaline Reaction*: Some potassium minerals after intense heating give an alkaline reaction on moist turmeric paper.

3. *Precipitation with Platinic Chloride*: When platinic chloride is added to a neutral or slightly acid solution containing potassium, a yellow precipitate is formed.

Praseodymium, Pr, 141.
Radium, Ra, 226.4.
See RADIUM, p. 87.
Rhodium, Rh, 103.
Rubidium, Rb, 85.
Ruthenium, Ru, 102.
Samarium, Sa, 150.
Scandium, Sc, 44.

SELENIUM, Se, 79.

1. *Odor*: Selenium minerals when heated strongly give a very peculiar odor, thought to be similar to that of radishes or decaying radishes. When selenium is abundant, brown fumes form and the coal is coated with silver white, possibly bordered by red.

SILICON, Si, 28.

1. *Gelatinous Silica*: Dissolve the mineral in nitric acid, (after fusion with soda if necessary), and continue boiling. As dryness is approached a jelly-like mass of metasilicic acid, H_2SiO_3, is formed.

2. *Separation of Silica Powder*: Many silicates, when finely powdered and boiled in acid, decompose and go into solution, except the silica, which remains as a very fine powder not easily detected

in the liquid. To determine whether or not the bulk of the mineral has been dissolved, filter, and evaporate a drop of the clear liquid on a clean glass plate. A considerable residue shows that the mineral has been decomposed.

3. *Detection of Aluminum, Iron, Calcium and Magnesium in Silicates*: Dissolve the mineral in dilute nitric acid, (after fusion with four parts of soda or borax, if necessary), carefully boil to dryness, and cool. Add a little strong hydrochloric acid and heat gently, add 5 volumes of water, boil and filter. (The residue on the paper should be silica, and soluble in potassium hydroxide.) Add a little nitric acid to the filtrate from the silica, boil, add ammonia until the solution is just alkaline. A light colored precipitate is aluminum, a dark colored one contains iron and possibly aluminum. Filter, save the filtrate, and if the precipitate is dark wash it into a test tube with water, add potassium hydroxide and boil to dissolve aluminum. Filter off the iron, add hydrochloric acid to the filtrate, boil, add ammonia to precipitate the aluminum. Heat to boiling the filtrate saved from the iron and aluminum, and add ammonium oxalate. Let it stand. The precipitate, if any, is calcium oxalate. Filter with two or three thicknesses of filter paper, add more ammonium oxalate, and, if necessary, run it through the same filter until a clear liquid is secured. Cool the filtrate, add sodium phosphate and strong ammonia to precipitate magnesium, and let it stand in a cool place. A precipitate shows the presence of magnesium.

4. *Skeleton of Silica in Salt of Phosphorus Bead*: When a powdered silicate is fused in a salt of phosphorus bead an insoluble mass of silica hangs in the bead.

SILVER, Ag, 108.

1. *Reduction to Metallic Silver with Soda*: Powder the silver mineral and fuse it on coal with three parts of soda. A bright, malleable, metal globule forms. Silver minerals containing only arsenic, antimony, sulphur or tellurium in addition to silver yield a metallic bead when roasted in the O.F. If lead and antimony are present a reddish to lilac coating is formed on the coal.

2. *Precipitation as Silver Chloride*: Dissolve the powdered mineral in strong nitric acid, add water and then a few drops of hydrochloric acid, or a little common salt. The white, or curdy white precipitate of silver chloride darkens on exposure to light, is soluble in ammonia, and may be reduced to metallic silver with soda on charcoal.

SODIUM, Na, 23.

1. *Flame Color*: Many sodium minerals powdered and applied to the flame give it a deep yellow color, invisible through dark blue glass. Others must be powdered and mixed with an equal volume of powdered gypsum and applied to the flame on a moistened platinum wire.

2. *Alkaline Reactions on Turmeric Paper*: Some sodium minerals after strong heating give an alkaline reaction on moist turmeric paper.

STRONTIUM, Sr, 88.

1. *Flame Color*: The powdered mineral gives a deep, intense crimson, intensified by moistening it with hydrochloric acid. It is much like the lithium flame, but is more intense and more persistent than the calcium flame. See number 2.

2. *Alkaline Reaction on Turmeric Paper*: Some strontium minerals after heating give an alkaline reaction on moist turmeric paper. Lithium minerals do not give an alkaline reaction.

3. *Precipitation of Strontium Sulphate*: A little sulphuric acid will precipitate white strontium sulphate from solutions not too dilute or too acid. The precipitate is not dissolved by boiling it in water. See similar test under calcium.

4. Strontium salts are heavier than most light colored minerals, but lighter than barium minerals.

SULPHUR, S, 32.

Tests for Sulphides.

1. *Sulphur Fumes in Open Tube and on Charcoal*: Powdered sulphides heated in the open tube, or in the O.F. on coal give the pungent odor of sulphur dioxide. Moistened blue litmus paper held at the end of the tube is turned red. Some sulphides give white fumes of sulphur trioxide in the open tube.

2. *Sublimate of Sulphur in Closed Tube*: Some sulphides heated in the closed tube yield sulphur which forms a dark yellowish brown deposit while hot, but changes to yellow when cold.

3. *Discoloration of Silver*: Fuse a powdered sulphide with soda on coal, and crush and moisten the mass on bright silver. A brownish black stain of silver sulphide is formed. Selenium and tellurium destroy this test.

4. *Separation of Sulphur by Solution in Nitric Acid*: When sulphides are dissolved in strong nitric acid, brownish red fumes are given off, and free sulphur may rise to the surface of the solution.

Tests for Sulphates:

1. *Barium Sulphate Precipitation*: Dissolve the mineral in dilute hydrochloric acid and add a few drops of barium chloride. A white precipitate of barium sulphate is formed. It is not dissolved by boiling it in water. See similar test under calcium.

2. *Discoloration of Silver*: Fuse the powdered mineral with its own volume of charcoal dust and two volumes of soda. The mass moistened and crushed on bright silver leaves a brownish black stain. The sulphate is reduced to a sulphide.

Tantalum, Ta, 183.

TELLURIUM, Te, 127.5.

1. *Violet Solution with Strong Sulphuric Acid*: The powdered mineral heated gently in concentrated sulphuric acid gives a beautiful reddish violet color. When water is added, the cooled solution loses its color and grayish black tellurium is deposited.

2. *White Coating on Charcoal*: When a telluride is heated on coal in the O.F. a heavy white coating of tellurium dioxide forms, and the flame is colored pale green.

3. *Violet Solution after Fusion with Soda and Charcoal*: Mix the powdered mineral with soda and charcoal dust and heat it in a rather wide closed tube. Cool and add water. The solution is reddish violet.

THALLIUM: Tl, 204.

All known thallium minerals give an intense green color to the flame when heated before the blowpipe. On charcoal in the reducing flame a thin, white coating of thallium oxide is formed. With bismuth flux on charcoal in the oxidizing flame thallium minerals give a coating similar to that formed by lead, but the flame is intensely green.

Thorium, Th, 232.5.

TIN, Sn, 119.

1. *Metallic Tin on Charcoal*: The powdered mineral mixed with its own volume of charcoal powder and two volumes of soda and fused on coal in the R.F. gives globules of white metallic tin,

which become dull on exposure to air. Long heating gives a white coating of tin oxide on the coal.

2. *Bead Coloration*: Color a borax bead pale blue with copper oxide. Add a little tin mineral and heat a moment in the R.F. The bead becomes brown or ruby red.

TITANIUM, Ti, 48.

1. *Salt of Phosphorus Bead Colors*: In the O.F. the bead is yellow when hot, and colorless when cold. In the R.F. it is yellow while hot, and beautiful faint violet when cold. Confirm by other tests.

2. *Violet Solution*: Fuse with borax or soda, dissolve in hydrochloric acid, add tin and boil. A violet color shows the presence of titanium.

3. *Reddish Yellow to Amber Color with Hydrogen Peroxide*: Fuse the mineral with soda, add a little concentrated sulphuric acid and an equal amount of water, boil until clear. Add cold water, then hydrogen peroxide. The solution becomes reddish yellow or amber colored if titanium is present.

TUNGSTEN, W, 184.

1. *Blue Solution with Tin*: Dissolve the mineral by long boiling in hydrochloric acid, (after fusion with soda, if necessary). A yellow powdery precipitate forms. Add a granule of tin and boil. The solution becomes blue, and with further boiling brown.

2. *Salt of Phosphorus Bead Color*: In the O.F. the bead is colorless. In the R.F. it is a fine blue.

URANIUM, U, 239.5.

1. *Salt of Phosphorus Bead*: In the O.F. it is yellow while hot, yellowish green when cold; in the R.F. it is green when cold.

2. *Yellow Precipitate*: The powdered mineral is dissolved in hydrochloric acid, or fused with soda, then dissolved in hydrochloric acid. Add ammonia until the solution is nearly neutral. (If a precipitate forms, add acid slowly until it is dissolved.) Add powdered ammonium carbonate until no more precipitate is formed, let it stand, filter, add hydrochloric acid until the filtrate is acid, boil, then add ammonia in excess. A yellow precipitate indicates uranium. Filter and test the precipitate with a bead. Dissolve the precipitate in a little dilute sulphuric acid, add zinc. A blue solution turning green confirms the other tests.

See also under Uraninite.

VANADIUM, V, 51.

1. *Borax Bead Colors:* In the O.F. the bead is yellow when hot, colorless when cold. In the R.F. it is dirty green when hot, fine green when cold.

2. *Salt of Phosphorus Bead Colors:* In the O.F. it is yellow to amber when hot, paler when cold. In the R.F. the bead is dirty green when hot, fine green when cold.

3. *A Faint Yellow Precipitate:* Fuse the powdered mineral in 4 parts soda and 2 parts niter. Dissolve the mass in hot water, filter, acidify with acetic acid, and add lead acetate. A pale yellow precipitate fading to white indicates vanadium. If molybdenum or chromium is suspected, dissolve the fused mass in water and add powdered ammonium chloride until it dissolves very slowly, and let the solution stand. A faint yellowish precipitate indicates vanadium. Filter and wash the precipitate with a solution of ammonium chloride, heat slowly in a porcelain crucible. A red residue is vanadium pentoxide.

4. *Changing Color of Solution:* Dissolve the mineral in sulphuric acid, (after fusion as in number 3, if necessary). Add metallic zinc. The solution changes to yellow, green, bluish green, blue, greenish blue, bluish violet and lavender.

5. Many vanadium-bearing minerals such as carnotite, vanadinite, descloizite, and others, when powdered and treated with concentrated hydrochloric acid give a rich red-brown solution. When water is added to the solution it changes to green or becomes colorless. If the solution is not too dilute, hydrogen peroxide will restore the color to red-brown. If metallic zinc is added the green color returns, but the solution gradually fades to colorless. Calcium vanadate must be treated longer to get the red-brown color.

If dilute acid is used the solution is generally greenish, yellowish (from uranium), or colorless. Hydrogen peroxide will bring the red-brown color, and zinc added will bring the green color or will decolorize the solution. Roscoelite and other vanadium-bearing silicates treated with dilute hydrochloric acid and allowed to stand some time, or boiled, will give good reactions.

Xenon, X, 128.
Ytterbium, Yb, 173.
Yttrium, Y, 89.

ZINC, Zn, 65.

1. *Coating on Charcoal*: Make a paste of equal volumes of the powdered mineral and soda and a little charcoal dust, heat strongly in the R.F. for some time. Metallic zinc is separated as a dust, becomes oxidized and forms a coating of zinc oxide which is pale yellow when hot and white when cold.

2. *Green Color with Cobalt Nitrate*: Light colored, infusible zinc minerals, (including light colored sphalerite), become dark green when made into a paste with cobalt nitrate solution and intensely heated on charcoal in the O.F. The coating formed in test 1, will give the same results. For zinc silicates, see 3.

3. *Blue Color with Cobalt Solution*: Zinc silicates powdered and moistened with cobalt nitrate and intensely heated in the O.F. become blue. Spots of green may occur.

4. *Flame Color*: When some zinc minerals are strongly heated in the R.F. metallic zinc is formed and burned at once, giving the flame streaks of pale bluish green light.

ZIRCONIUM, Zr, 91.

1. *Alkaline Reaction on Turmeric Paper*: Powder the mineral and fuse a little in soda on a platinum wire. Dissolve the bead in a little hydrochloric acid. Turmeric paper is reddened by the solution.

IMPORTANT MINERALS GROUPED BY COLOR

I. METALLIFEROUS MINERALS OF METALLIC LUSTER GROUPED BY COLOR.

The symbol indicates the important metal contained.

Black

(Some of these appear in other groups)

Alabandite, Mn	172
Allanite, Ce, Di, La	253
Argentite (to gray), Ag	230
Arsenic	240
Bismuth (rarely), Bi	245
Bournonite, Pb, Cu, Sb	214
Braunite, Mn	171
Brookite, Ti	182
Cassiterite, Sn	221
Chalcocite, Cu	198
Chromite, Cr	168
Columbite, Nb, Ta	252
Cuprite (rarely), Cu	203
Emery (Abrasive)	81
Enargite, Cu, (Ag)	199
Ferberite, W	186
Fergusonite, Nb, Y, Er, Ce, Ta, etc	
Franklinite, Zn, Mn	218
Galena, Pb	208
Göthite, Fe	160
Graphite, C	93, 100
Hausmannite, Mn	173
Hematite, Fe	158
Ilmenite, Fe, Ti	161
Iron, native, Fe	162
Jamesonite, Pb	213
Limonite, Fe	160
Magnetite, Fe	159
Manganite, Mn	170
Melaconite, Cu	203
Menaccanite, Fe, Ti	161
Metacinnabarite, Hg	250
Molybdenite, Mo	173
Octahedrite, Ti	182
Perovskite, Ti	
Polianite, Mn	172
Polybasite, Ag	233
Psilomelane, Mn	170
Pyrolusite, Mn	169
Pyrargyrite, Ag	321
Rutile (to brown), Ti	181
Samarskite, U, Nb, Ta	256
Siderite, Fe	161
Stephanite, Ag	232
Stibnite (rarely), Sb	243
Stromeyerite, Ag	231
Tantalite, Ta	255
Tennantite, Cu (Ag)	202
Tenorite, Cu	203
Tetrahedrite, Cu	201
Turgite, Fe	161
Uraninite, U	190
Wad, Mn, etc	172
Wolframite, W	186

BLUE

Covellite, Cu	204

BRASS, BRONZE, COPPER-RED, YELLOW

(Some of these appear in other groups)

Arsenopyrite, Fe, As	164
Bismuth, Bi	245
Bornite, Cu	201
Calaverite (when tarnished) Au, Ag	228
Chalcopyrite, Cu	200
Copper, Cu	199
Domeykite, Cu	208
Empressite, Ag	235
Enargite, Cu, (Ag)	199
Göthite, Fe	160
Gold	227
Krennerite, Au	229
Marcasite, Fe	163
Millerite, Ni	176
Niccolite, Ni, As	177
Orpiment (non-metallic), As	241
Pentlandite, Ni	177
Pyrite, Fe	162, 200
Pyrrhotite, Fe, (Ni)	164

BROWN

(Some of these appear in other groups)

Allanite, Ce, Di, La	253
Bornite (tarnish), Cu	201
Brookite, Ti	182
Cassiterite, Sn	221
Cuprite, Cu	203
Enargite, Cu, (Ag)	199
Gadolinite, Be, Y, etc	257
Göthite, Fe	160
Hausmannite, Mn	173
Hematite, Fe	158
Hübnerite (to black), W, (Mn)	187
Limonite, Fe	160
Octahedrite, Ti	182
Perovskite, Ti	
Pyrrhotite, Fe, Ni	164
Rutile, Ti	181
Sphalerite, Zn	216
Turgite, Fe	161
Uraninite, U	190
Wad, Mn, etc	172
Wolframite, W	186

GRAY (see also WHITE)

(Some of these appear in other groups)

Aikinite, Pb, Bi, Cu	211
Antimony	242
Argentite, Ag	230
Arsenic	240
Arsenopyrite, Fe, As	164
Bismuthinite, Bi	245
Bournonite, Pb, Cu, Sb	214
Chalcocite, Cu	198
Cobaltite, Co	179
Cosalite, Pb, Bi	211
Emplectite, Cu, Bi	208
Enargite, Cu, (Ag)	199
Galena, Pb	208
Graphite, C	93
Hematite, Fe	158
Hessite, Ag, Au	234
Iron, metallic	162
Jamesonite, Pb	213
Linnaeite, Co, Ni	180
Löllingite, Fe, As	164
Magnetite, Fe	159
Manganite, Mn	170
Marcasite, Fe	163
Melaconite, Cu	203
Molybdenite, Mo	173
Palladium, Pa	239
Platinum, Pt	237
Polianite, Mn	172
Polydymite, Ni	

Psilomelane, Mn	170
Pyrargyrite, Ag	231
Pyrolusite, Mn	169
Rutile, Ti	181
Smaltite, Co, (Ag)	178
Sperrylite, Pt	238
Sphalerite (rarely), Zn	216
Stannite, Sn, Cu	221
Stephanite, Ag	232
Stibnite, Sb	243
Sylvanite, Au, Ag	227
Tennantite, Cu, (Ag)	202
Tetradymite, Bi	247
Tetrahedrite, Cu, (Ag)	201
Wad, Mn, etc.	172
Wolframite, W	186
Zinkenite, Pb, Sb	214

RED

(Some of these appear in other groups)

Bismuth	245
Bornite, Cu	201
Cinnabar, Hg	249
Copper, Cu	199
Cuprite, Cu	203
Empressite (bronze), Ag	235
Göthite, Fe	160
Hematite, Fe	158
Niccolite, Ni, As	177
Proustite, Ag	231
Pyrargyrite, Ag	231
Pyrrohtite, Fe, Ni	164
Realgar, As	239
Rutile, Ti	181
Turgite, Fe	161
Zincite, Zn	217

WHITE

(Some of these appear in other groups)

Allemontite, As, Sb	241
Altaite (to yellowish), Pb	213
Amalgam, Ag, Hg	234
Antimony	242
Arsenic, As	240
Arsenopyrite, Fe, As	164
Bismuth, Bi	245
Bismuthinite, Bi	245
Calaverite, Au	228
Chloanthite, Ni, Co	178
Cobaltite, Co	179
Domeykite, Cu	208
Dyscrasite, Ag	236
Emplectite, Cu, Bi	208
Galena, Pb (gray)	208
Gersdorffite, Ni	177
Iridium, Ir	238
Iridosmine, Ir, Os	238
Krennerite, Au	229
Linnaeite, Co, Ni	180
Löllingite, Fe, As	164
Marcasite, As (whitish)	163
Mercury, Hg	250
Palladium, Pa	239
Platinum, Pt	237
Silver, Ag	229
Smaltite, Co, (Ag)	178
Sperrylite, Pt	238
Stibnite, Sb	243
Sylvanite, Au, Ag	227
Tellurium, Te	248
Tetradymite, Bi	247
Tetrahedrite, Cu, (Ag)	201

II. METALLIFEROUS MINERALS OF UNMETALLIC LUSTER GROUPED BY COLOR

The symbol indicates the important metal contained.

Black

(Some of these appear in other groups)

Alabandite, Mn	172
Columbite, Nb, Ta	255
Gahnite, Zn	220
Melaconite, Cu	203
Proustite, Ag	231
Pyrargyrite, Ag	231
Samarskite, U, Nb, Ta	256
Tenorite, Cu	203
Thorite, Th	256
Yttrotantalite, Ta, Nb, Y	

Brown

(Some of these appear in other groups)

Gummite, U	192
Mimetite, Pb	212
Olivenite, Cu, As	207
Scheelite, W	187
Scorodite, Fe, As	166
Smithsonite, Zn	216
Vivianite, Fe	165
Willemite, Zn	218

Brown to Black

(Some of these appear in other groups)

Allanite, Ce, Di, La	253
Brookite, Ti	182
Cassiterite, Sn	221
Descloizite, Pb, Zn	215
Gadolinite, Be, Y, etc.	257
Göthite, Fe	160
Hematite, Fe	158
Hübnerite, W, (Mn)	187
Octahedrite, Ti	182
Proustite, Ag	231
Sphalerite, Zn	216
Titanite, Ti	49
Wolframite, W	186
Wurtzite, Zn	219

Blue to Violet

(Some of these appear in other groups)

Azurite, Cu	202
Cerargyrite (voilet), Ag	233
Chalcanthite, Cu	207
Corundum, Al	81
Vivianite, Fe	165

Green and Greenish

(Some of these appear in other groups)

Atacamite, Cu	206
Brochantite, Cu	204
Bromyrite, Ag	235
Cerargyrite, Ag	233
Dioptase, Cu	207
Embolite, Ag	234
Gahnite, Zn	220
Iodobromite, Ag	92
Iodyrite, Ag	235
Leadhillite, Pb	
Libethenite, Cu	207
Malachite, Cu	202
Olivenite, Cu, As	207
Phosgenite, Pb	214
Pyromorphite, Pb	210
Scorodite, Fe, As	166
Smithsonite, Zn	216
Stolzite, W, Pb	188
Titanite, Ti	49
Torbernite, U, Cu	195
Uranocircite, U	198

RED

(Some of these appear in other groups)

Cinnabar, Hg	249
Crocoite, Cr, Pb	215
Goslarite, Zn	220
Orpiment, As	241
Proustite, Ag	231
Pyrargyrite, Ag	231
Realgar, As	239
Sphaerocobaltite, Co	
Titanite (rose), Ti	49
Uranosphaerite, U, Bi	195

RED TO BROWN

(Some of these appear in other groups)

Cerite, Ce	254
Corundum, Al	81
Cuprite, Cu	203
Descloizite, Pb, Zn	215
Göthite, Fe	160
Hematite, Fe	158
Hübnerite, W	187
Monazite, Ce, La, Th	254
Rutile, Ti	181
Sphalerite, Zn	216
Titanite, Ti	49
Valentinite, Sb	244
Vanadinite, V, Pb	193
Wulfenite, Mo, Pb	174
Xenotime, Y	

WHITE TO GRAY

(Some of these appear in other groups)

Anglesite, Pb	209
Arsenolite, As	242
Calamine, Zn	217
Calomel, Hg	250
Cerargyrite, Ag	233
Cerite, Ce	254
Cerussite, Pb	209
Corundum, Al	81
Erythrite, Co, As	180
Gahnite, Zn, Al	220
Gibbsite, Al	223
Goslarite, Zn	220
Leadhillite, Pb	
Octahedrite, Ti	182
Olivenite, Cu, As	207
Penfieldite, Pb	
Phosgenite, Pb	214
Proustite, Ag	230
Pyrargyrite, Ag	230
Pyromorphite, Pb	210
Scheelite, W	187
Senarmonite, Sb	244
Siderite, Fe	161
Smithsonite, Zn	216
Sphalerite, Zn	216
Stolzite, Pb, W	188
Tellurite, Te	248
Titanite, Ti	49
Valentinite, Sb	244
Vivianite, Fe	165
Wolframite, W	186
Wulfenite, Pb, Mo	174
Xenotime, Y	

YELLOW TO ORANGE

(Some of these appear in other groups)

Anglesite, Pb	209
Autunite, U	195
Bromyrite, Ag	235
Calomel, Hg	250
Cassiterite, Sn	221
Corundum, Al	81
Embolite, Ag	234
Goslarite, Zn	220
Greenockite, Cd	251
Gummite, U	192
Iodobromite, Ag	92
Iodyrite, Ag	235
Leadhillite, Pb	
Mimetite, Pb	212

Orpiment, As	241
Pyromorphite, Pb	210
Realgar, As	239
Scheelite, W	187
Sphalerite, Zn	216
Tellurite, Te	248
Titanite, Ti	49
Uranocircite, U	198
Uranophane, U	195
Uranosphaerite, U	195
Vanadinite, V, Pb	193
Wulfenite, Mo, Pb	174
Xenotime, Y	
Yttrotantalite, Ta, Nb, Y	

III. NON-METALLIC MINERALS OF ECONOMIC VALUE GROUPED BY COLOR

BLACK

(Some of these may appear in other groups)

Asphalts	114
Bitumens	114
Bort	94
Carbonado	94
Coals	96-100
Graphite	93
Plumbago	93

BLUE TO PURPLE

(Some of these may appear in other groups)

Amblygonite	124
Amethyst	153
Apatite	130
Barite	85
Borax	88
Brucite	128
Celestite	143
Corundum	81
Fluorite	121
Gypsum	71
Lepidolite	122
Sylvite	132

BROWN

(Some of these may appear in other groups)

Apatite	130
Asphalts	114
Barite	85
Bitumens	114
Chili niter	138
Lignite (some)	99
Magnesite	126
Strontianite	143
Sulphur	146

COLORLESS, WHITE, GRAY

(Some of these may appear in other groups)

Alums	82, 222
Alunite	134
Amblygonite	124
Apatite	130
Barite	85
Barytocalcite	86
Boracite	89
Borax	88
Bort	94
Brucite	128
Carnallite	132
Celestite	143
Chili niter	138
Colemanite	89
Corundum	81
Epsomite	128
Fluorite	121
Glauberite	139
Gypsum	71
Halite	138
Hanksite	141
Kainite	133

Kalinite	134
Lepidolite	122
Lithiophilite	124
Magnesite	126
Mirabilite	138
Natron	140
Niter	133
Petalite	126
Saltpeter	133
Sassolite	91
Spodumene	122
Stassfurtite	89
Strontianite	143
Sylvite	132
Thenardite	141
Triphylite	124
Trona	140
Ulexite	90
Witherite	86

GREEN

(Some of these may appear in other groups)

Amblygonite	124
Apatite	130
Boracite	89
Borax	88
Fluorite	121
Spodumene (yellowish)	122
Stassfurtite	89
Strontianite	143

RED AND REDDISH

(Some of these may appear in other groups)

Alunite	134
Apatite	130
Barite	85
Brucite (pink)	128
Carnallite	132
Celestite	143
Corundum	81
Glauberite	139
Gypsum	71
Halite	138
Kainite	133
Sulphur	146

YELLOW

(Some of these may appear in other groups)

Aluminite	84
Alunogen	130
Amber	119
Apatite	130
Barite	85
Boracite	89
Celestite	143
Chili niter	138
Colemanite	89
Glauberite	139
Halite	138
Hanksite	141
Sassolite	91
Stassfurtite	89
Strontianite	143
Sulphur	146
Sylvite	132
Thenardite	141
Witherite	86

IV. GEMS AND SEMI-PRECIOUS STONES

BLUE, PURPLE

(Some of these may appear in other groups)

Amethyst	153
Moonstone	151
Opal (bluish)	151
Sapphire	154
Sapphire quartz	154
Spinel	154
Topaz	155
Turquoise	156

GREEN

(Some of these may appear in other groups)

Amazonstone	149
Aquamarine	149
Beryl	149
Bloodstone	153
Californite	150
Chrysoberyl	150
Emerald	151
Emerald (oriental)	152
Epidote	151
Heliotrope	153
Hiddenite	151
Olivine	48
Opal	151
Plasma	154
Prase	154
Spinel	154
Turquoise	156

WHITE-GRAY, COLORLESS

(Some of these may appear in other groups)

Californite	150
Chalcedony	153
Diamond	151
Moonstone	151
Opal	151
Phenacite	152
Rock Crystal	154

ROSE, RED AND PINK

(Some of these may appear in other groups)

Garnet	63
Hyacinth	151
Jasper	153
Kunzite	151
Opal	151
Phenacite	152
Rose quartz	154
Rubellite	154
Ruby	81, 154
Spinel	154
Topaz	155

YELLOW

(Some of these may appear in other groups)

Citrine	153
Epidote	55
Jasper	153
Olivine	48
Opal	157
Peridot	152
Phenacite	152
Spinel	154
Topaz	155
Topaz (oriental)	152

THE COMMON ROCKS

Rocks May Be Divided into Three Great Classes:

1. IGNEOUS.
2. SEDIMENTARY.
3. METAMORPHIC.

IGNEOUS ROCKS

Igneous rocks are those which have resulted from the solidification of molten rock matter. They make up by far the largest part of the solid earth.

Analyses of thousands of igneous rocks show that they consist mainly of the eight elements: oxygen, silicon, aluminum, iron, magnesium, potassium, sodium and calcium. The quantity of oxygen present is commonly sufficient to unite with the other seven elements and form their oxides; thus: silicon dioxide or silica (SiO_2), aluminum oxide or alumina (Al_2O_3), iron monoxide or ferrous oxide (FeO), iron sesquioxide or ferric oxide (Fe_2O_3), magnesium oxide or magnesia (MgO), potassium monoxide (K_2O), sodium monoxide (Na_2O), calcium monoxide or lime (CaO). For convenience in showing the chemical composition of rocks, it is customary to write the analyses in percentages of the several oxides; thus, in the granite group, the average percentages of these oxides, as shown by several hundred analyses, are as follows: SiO_2 70.0; Al_2O_3 15.0; $Fe_2O_3 + FeO$ 2.6; MgO 0.64; CaO 1.7; Na_2O 3.2; K_2O 4.0. These form 97.14 per cent of the rock. The remaining 2.86 per cent is composed mainly of small quantities of the oxides of rarer elements.

Analyses of rock-making minerals naturally show that these eight elements predominate, and, further, that the oxygen present is sufficient to unite with the other elements to form the oxides mentioned above.

Some geologists believe that molten rock masses are composed mainly of these oxide molecules, while others hold that they are made up of mineral molecules. If the first view is correct the process of crystallization includes the combination of the oxides into mineral molecules and the building of these molecules into crystals or crystal grains. If the second view is right crystallization means only the assembling and orderly arranging of the mineral molecules into crystals. According to the first view the building of an anorthite crystal would require: the coming together of a molecule of CaO, a molecule of Al_2O_3 and two molecules of SiO_2 to form the anorthite molecule $CaAl_2Si_2O_8$, and the coming together of multitudes of these molecules and their orderly arrangement into a crystal of anorthite. If the second theory is correct the building of the crystal would require only the orderly arrangement of anorthite molecules already present in the molten mass.

The solidification of a rock may take place under conditions which would permit the entire mass to crystallize. The rock so formed would be *holocrystalline,* that is, completely crystalline. Or the solidification may take place under conditions which permit only a part of the mass to crystallize, while the remainder solidifies as an amorphous or unorganized mass of molecules in the form of a rock glass. Such a rock is said to be glassy. If conditions were very unfavorable the whole mass might solidify as a rock glass. A rock so formed is called a glass.

The composition of the magma will decide what minerals may be formed when it solidifies. And the conditions under which it solidifies will decide the completeness or incompleteness of the crystallization.

Molten rocks behave as though they were solutions of minerals in minerals, and no matter what their temperatures may be the crystallization of minerals will begin when the solution reaches the saturation point for those minerals. The higher the temperature of a magma the more liquid it is, and the lower the temperature the more viscous it is. In crystal building the molecules of a mineral are attracted to one another, but to get to the point at which the crystal is building they must travel through the molten mass. It is plain that a high degree of liquidity makes the movement of the molecules easy, while high vicosity hinders and may completely stop it. As a rule the magmas high in silica are more viscous than those low in silica at the same temperature. As a result, rock glasses showing a high percentage of silica are common, while rock glasses low in silica are not common.

If a rock magma is exposed to sudden cooling many centers of crystallization will be set up and the resulting crystal grains will be small. But if the cooling is very slow fewer centers are formed and the crystals have larger areas from which to draw their molecules and will, as a consequence, grow to larger size. Molten rocks poured out upon the earth's surface are subjected to sudden cooling and as a result are fine textured. Molten rocks which do not reach the surface, but remain covered, cool more slowly and as a result are coarser textured.

It is proved by experiment that some rock-making minerals will crystallize only in the presence of certain substances which act as fluxes or solvents. These substances are known as *mineralizers*. The more important of these are water, hydrofluoric acid, boracic acid, carbon dioxide, and chlorine.

On the other hand, a number of the important rock-making minerals will crystallize from "dry fusion" or a "melt" containing neither water nor the other mineralizers. It is doubtful whether any rock magmas in their natural conditions are absolutely "dry fusions." It is likely that all rock magmas contain water and one or more of the other mineralizers, but the amount may be very small.

When a rock is poured out of a volcano the mineralizers have a chance to escape before they have done their work. On the other hand, there is little chance for the mineralizers to escape from a rock which cools under cover and they remain to aid the formation of crystals.

The conditions most favorable for complete crystallization of a molten rock are:

1. The cooling of the magma should begin from a temperature at which it is decidedly liquid.
2. It must cool slowly and uniformly.
3. It must contain certain substances known as mineralizers.

TEXTURE

The size of the mineral grains formed in the solidification of a molten rock depends upon many factors, of which the most important appear to be:

1. The composition of the magma.
2. The temperature at which solidification begins.
3. The rate of cooling.
4. The presence and abundance of mineralizers.
5. The pressure to which the solidifying mass is subjected.

The rock-making minerals differ widely in their temperatures of fusion. A rock mass composed of a single mineral without mineralizers would be molten at the fusion temperature of that mineral. It would also be on the very point of solidification. If to such a rock mass another mineral is added, the two may act as fluxes to one another and the mass may stay molten at a temperature far below the fusion point of either. A third mineral added may have a similar effect and still further reduce the melting points of the minerals. This is nicely illustrated in the smelting of ores. The skillful smelter knows that heat and chemical reactions will often do what heat alone will not do, and so he selects a *flux* which will react with the impurities of his ore and form a solution at a temperature far lower than that necessary to melt these impurities by heat alone. Now, if the melting point of the rock mass is lowered by this fluxing power of the minerals, the time of cooling and solidification is prolonged, and as a consequence the mineral grains grow larger.

The mineralizers are even more effective fluxes for the rock-making minerals than are those minerals for one another. From this it is evident that their presence will greatly lower the melting points of the minerals, or, what is the same thing, lower the temperature at which crystallization begins. This means the lengthening of the period during which crystal growth may take place, and the formation of larger crystals.

It has been stated above that the presence of mineralizers is necessary to the crystallization of certain rock-making minerals, but it is not necessary to the crystallization of others. The important rock-makers fall into the two groups as follows:

Mineralizers Necessary to Crystallization.	Mineralizers Unnecessary to Crystallization.
Quartz,	Olivine,
Albite,	Pyroxenes,
Orthoclase,	Oligoclase,
Sanidine,	Andesine,
Hornblende,	Labradorite,
Biotites (some),	Anorthite,
Muscovite,	Leucite,
Tourmaline,	Nephelite.
Sodalite.	

The minerals of the first group are characteristic of acidic rocks such as the granite class, while those of the second group are characteristic of the basic rocks such as the gabbro class.

A study of the acidic and the basic rocks leads to the conclusion that mineralizers are present in much greater abundance in the magmas of acidic rocks than in those of basic rocks. If this is true it follows that when other conditions are the same the acidic rocks will cool to lower temperatures before complete solidification than will the basic rocks. This would give a longer period of crystal growth.

But acidic rock magmas are commonly more viscous than basic magmas, and viscosity hinders the growth of crystals.

Pressure raises the melting point of those minerals which expand on passing from the solid to the liquid form, and so shortens the period of solidification. This would naturally tend to cause the formation of small crystal grains. On the other hand, it is believed that high pressure is necessary to the formation of phenocrysts.

FORMS OF MINERAL GRAINS AND THE ORDER OF CRYSTALLIZATION

In the solidification of a rock, if all the minerals started to crystallize at the same moment, and completed their growth at the same moment, they would interfere with one another, and perfect crystal outlines would rarely occur. But a careful examination of the shapes of the mineral grains shows that certain minerals approach a perfect crystal outline much more commonly than do certain others. This results from the fact that some minerals begin to form earlier than others, and may even complete their growth without interference. This is true of the phenocrysts of porphyries. Thus, in a granular rock such as granite we may find mineral grains with almost perfect crystal outline; others with one, two or three crystal lines; and others with entirely irregular outlines. In general, it is found that the order of crystallization of the important rock-making minerals is magnetite, olivine, pyroxene, hornblende, biotite, muscovite, plagioclase, orthoclase, quartz, microcline.

From the statements in the foregoing paragraphs it is clear that there will be a very wide range of *texture* or *grain-size* in igneous rocks. On the one extreme will be the non-granular rock glasses in which even a powerful microscope shows no division of the mass into grains formed during the process of solidification. On the other will be the pegmatites whose crystals of feldspar, quartz and mica may reach a diameter of several feet. It seems desirable for the purpose of this bulletin to adopt textural terms in keeping with the simple field classification of igneous rocks proposed by Cross, Iddings, Pirsson and Washington in *The Quantitative Classification of Igneuos Rocks.* (See page 305.)

TEXTURAL GROUPS

1. The Granitoid Group: Igneous rocks composed of mineral grains large enough to be seen by the unaided eye.

2. The Felsitoid Group: All very fine textured igneous rocks composed largely, or wholly, of mineral grains too small to be distinguished by the unaided eye. Larger crystals (phenocrysts), may be present as in the porphyries; and glassy or uncrystallized rock matter may be present in amount too small to give the rock a glassy luster.

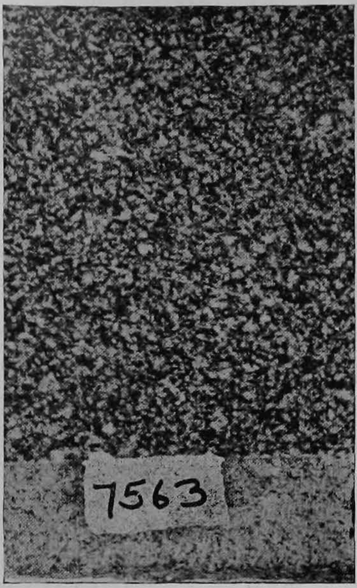
3. The Glassy Group: Igneous rocks having a glassy luster, and which are clearly composed, wholly or largely of glass.

4. Porphyritic Texture or Fabric: When a rock contains large crystals in a finer-grained groundmass, the large crystals are called phenocrysts, or porphyry crystals, and the rock is known as porphyry. The phenocrysts are the result of an earlier period of crystallization, during which comparatively few centers of crystal-building existed. These crystals reached a considerable size before a change in the physical or chemical conditions of the molten mass caused a more rapid and complete solidification, either by crystallization or by chilling to a rock glass, or both. The product of the later period of solidification is called the groundmass, and is usually of rather uniform texture.

5. Even-Grained Texture or Fabric: When the mineral grains of a rock have about the same average diameter, the rock is said to have an even-grained texture or fabric.

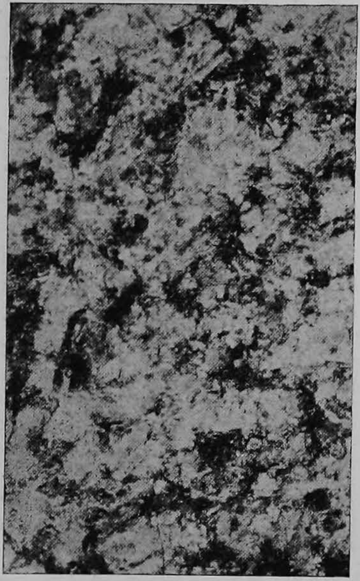
The granitoid rocks are divided into: (a) coarse-grained, when the mineral grains are one-quarter inch or more in diameter; (b) medium-grained, when the grains range from one-quarter to one-eighth inch in diameter; (c) fine-grained, when they range from one-eighth inch in diameter down to the smallest the eye can detect.

The textural terms in each of the following groups are more or less exactly equivalent, and are in use.

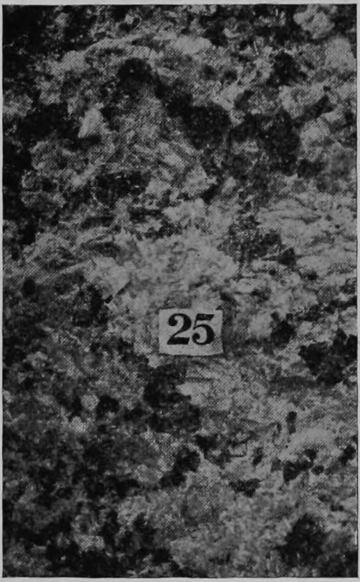


Fine texture
(granite)

Medium texture
(granite)

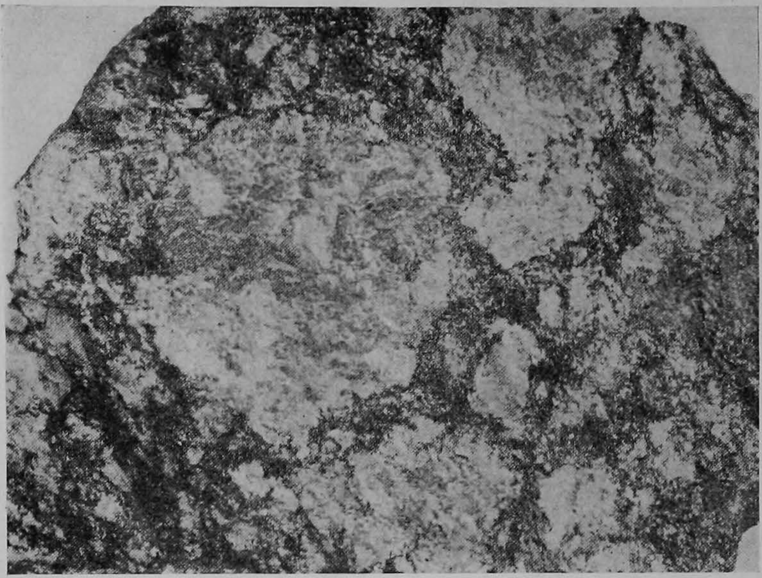


Coarse texture
(granite)

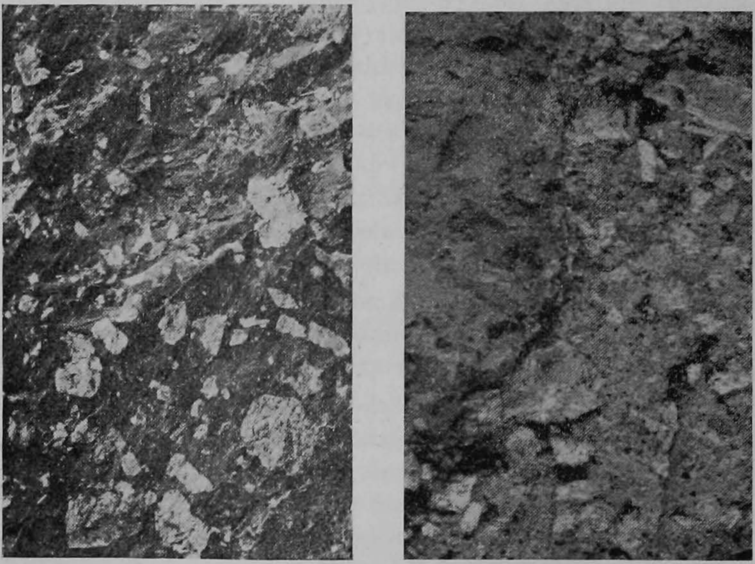


Uneven texture
(granite)

THE GRANITOID GROUP



Porphyritic granite

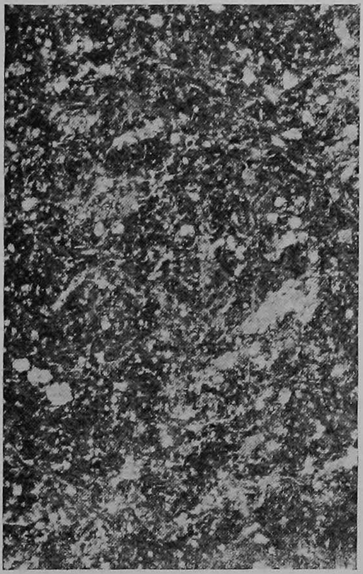


Quartz-feldspar porphyry

Syenite porphyry

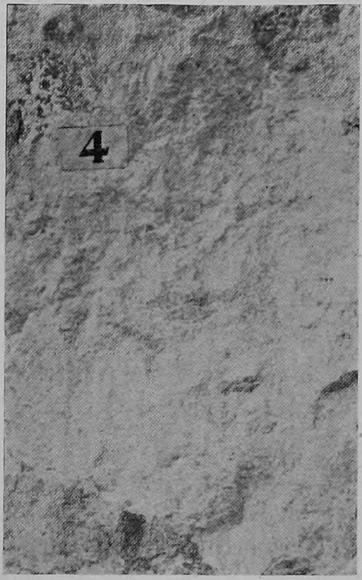
PORPHYRITIC TEXTURE OR FABRIC

Glassy texture (obsidian)
Yellowstone Park



Glassy and porphyritic texture
(pitchstone porphyry)

Georgetown, Colo.



Felsitic texture
(felsite)

Boulder, Colo.

FELSITOID AND GLASSY TEXTURAL GROUPS

1. GRANITOID, grained, granitic, phanero-crystalline, phaneritic, macrogranular, eye-grained.

2. FELSITOID, felsitic, aphanitic, dense, compact, stony, microgranular, lens-grained.

3. GLASSY, non-granular.

OCCURRENCE OF IGNEOUS ROCKS

Igneous rocks are grouped, according to their mode of occurrence, into INTRUSIVE and EXTRUSIVE rocks. Intrusive rocks are those formed by the solidification of molten rock matter which has risen to a point near the surface, but has cooled under a cover of rocks. Extrusive rocks are those formed by the solidification of rock matter which has been forced out upon the surface of the earth through volcanic or other vents.

INTRUSIVE: Bodies of intrusive rock are classified according to their form as: dikes, sheets, laccoliths, batholiths, necks or plugs, and stocks or bosses.

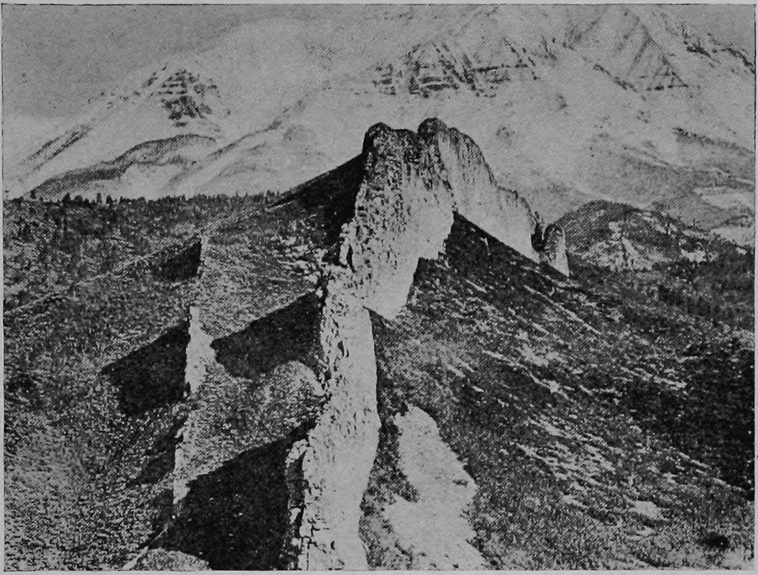
DIKES are the result of the solidification of molten rock in fissures. They are, as a rule, many times as long as wide (or thick), and they commonly reach the surface in a direction approaching the vertical.

SHEETS are masses of rock which in their ascent toward the surface have spread out between the strata of a sedimentary series. Near Golden sheets have been formed by the burial of surface flows (extrusive) beneath sedimentary beds.

LACCOLITHS: When a sheet is so thickened as to form a lenticular mass noticeably arching the overlying strata, it becomes a laccolith.

BATHOLITHS are great, irregular masses, often hundreds or thousands of square miles in area. They are mostly associated with the areas of very ancient rocks, and are frequently in contact with schists and gneisses.

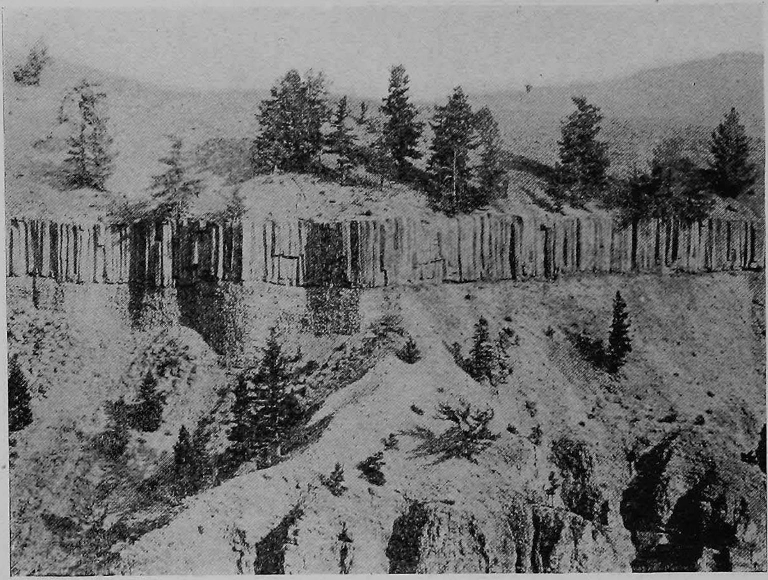
NECKS AND PLUGS are roughly cylindrical or spine-like columns of volcanic rock projecting from what are believed to be the conduits or throats of extinct volcanoes. They are supposed to result from the solidification of the magma which filled the conduit, and their projection above the surface is due to their greater resistance to erosion than the volcanic cone or the rock through which they project. Examples are to be seen in the Bear River valley near Yampa.



Dikes
Spanish Peaks, Colo.

Greenstone dikes
North of Lake Huron, Ontario

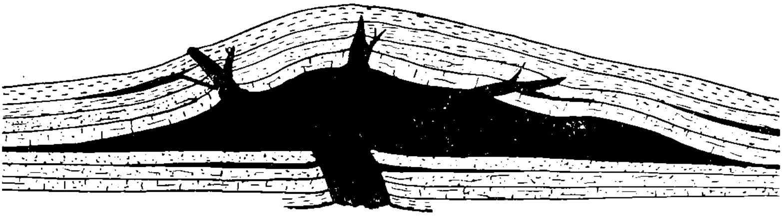
FORMS OF IGNEOUS ROCK BODIES



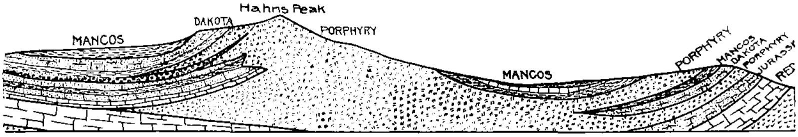
Sheet of basalt
Yellowstone Park

Volcanic neck
Yampa Valley, Colo.

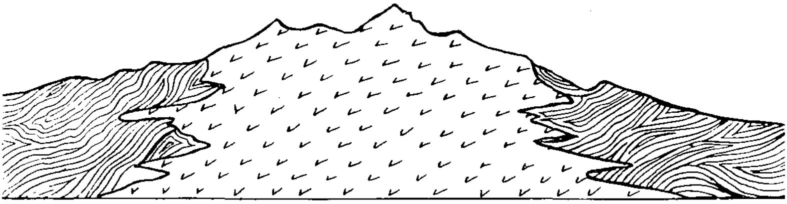
FORMS OF IGNEOUS ROCK BODIES



Section through a laccolith before erosion

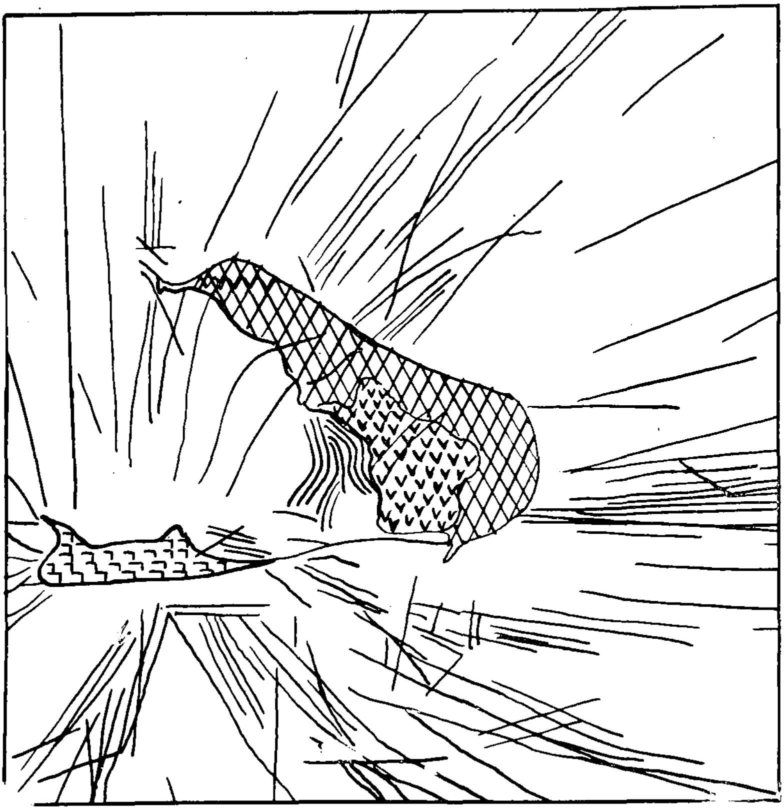


Section through an eroded laccolith
Hahn's Peak, Colo.

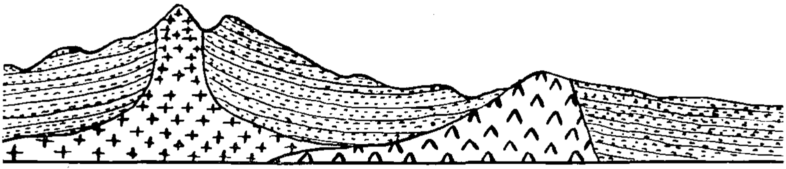


Section through a batholith

FORMS OF IGNEOUS ROCK BODIES

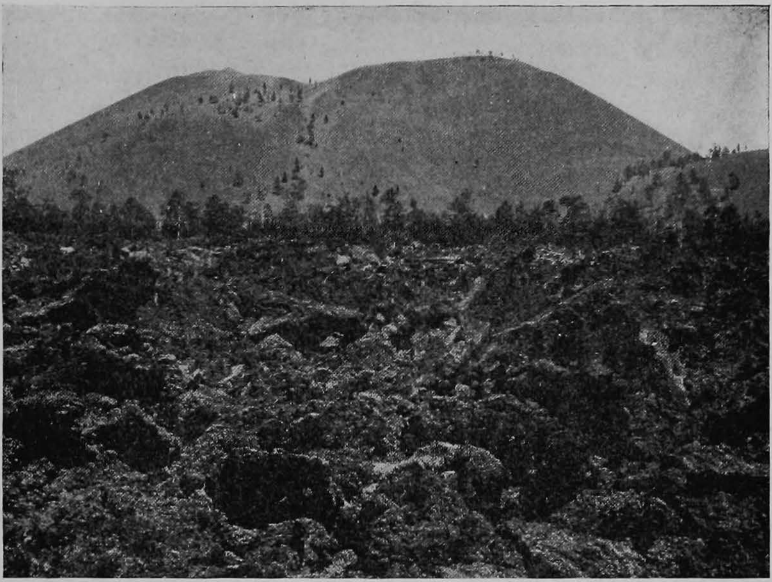


Outcrops of stocks and dikes
Spanish Peaks, Colo.



Section from southwest to northeast through stocks shown
in the preceding illustration
Spanish Peaks, Colo.

FORMS OF IGNEOUS ROCK BODIES



Cinder cone and lava flows
Arizona

Series of lava flows
Snake River, Idaho

FORMS OF IGNEOUS ROCK BODIES

STOCKS OR BOSSES are rounded masses of igneous rock somewhat resembling necks, but usually of greater size. The openings through which the rock rose to its present position may never have reached the surface. Several stocks occur in the San Juan region.

EXTRUSIVE: Extrusions of rock occur in three general ways: (a) wellings from fissures; (b) welling volcanic eruptions of molten rock, sometimes more or less mingled with fragments of solid rock; (c) explosive volcanic eruptions. In several parts of the earth large areas have been covered by sheets of lava which has welled up through fissures and flowed out over the surface of the earth. In some instances numerous sheets have succeeded one another and resemble the strata of a sedimentary series. The Snake and Columbia River areas and parts of the San Juan area furnish good examples of this mode of occurrence. Potosi Peak is carved out of a series of lava flows. Sheets of this kind are likely to be of fairly uniform thickness and of wide extent.

The eruptions of many volcanoes consist mainly of quiet up-wellings of lava, until the craters are filled and the molten rock flows down the slopes, or until the pressure of the lava upon the crater walls breaks them and the lava flows out through the gap. Sheets or flows formed in this way are likely to be of irregular thickness, stream-like in cross-section, and of no great lateral extent.

Some volcanoes erupt with explosive violence and send out vast volumes of solidified rock matter in fragmental form. Such material is classified, according to its degree of fineness, into dust, ash, lapilli, bombs, blocks. The finer material, when consolidated, is called tuff; the coarser forms, breccia and agglomerate.

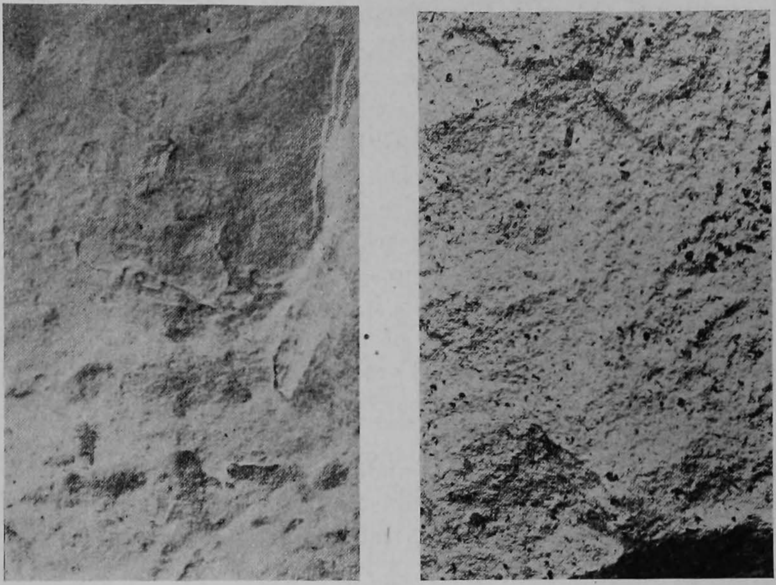
CLASSIFICATION OF IGNEOUS ROCKS

Minerals are made up of the elements combined in definite proportions. Thus quartz is always composed of one atom of silicon combined with two atoms of oxygen. Orthoclase consists of one molecule of potassium oxide, one molecule of alumina and six molecules of silica. Igneous rocks are composed of minerals or mineral substances, but as there is no fixed proportion in which minerals combine in forming rocks there can be no naturally fixed compositions for the different kinds of rocks. If we take a dozen rocks composed of quartz, feldspar, mica and hornblende, the mineral composition is the same throughout, but the proportions of these minerals may differ so widely that the rocks may show very little likeness in color or chemical composition. They may differ just as widely in texture. Some may be extrusive rocks, while others are intrusive. Some may have solidified millions of years ago, while others may have come from the last eruption of an active volcano.

Almost all minerals crystallize, and in the process of crystallization the molecules arrange themselves in a very definite order. Most igneous rocks are made up of crystallized matter, but the ''crystallizing'' of a rock consists in the crystallization of mineral after mineral, from a solution of minerals until the whole mass becomes an aggregate of mineral grains. In the finished rock there is no definite ratio between the various minerals and no fixed order or arrangement of the grains.

We have already seen that under varying conditions a molten mass may crystallize into large mineral grains, or into small ones, or may solidify as a glass. A mineral in crystallizing tends to take on a well defined crystal form. A rock shows no such tendency.

It is plain that there is a definiteness about minerals which rocks do not possess. As a result minerals are easily classified, while the classification of rocks presents many difficulties. There has been comparatively little difference of opinion in the broad, general classification of minerals, but the classification of igneous rocks has been a matter of unending disagreement. Classifications have been based upon various features such as: mineral composition, chemical composition, texture, origin and age. In almost any classification that may be suggested, arbitrary and artificial dividing lines must be drawn between the rock groups, and between the rocks in the groups. The commonly used grouping of igneous rocks presented in this text is based upon the kinds and proportions of the minerals composing the rocks, the textural differences, and to some extent upon the chemical composition. In the discussion of the various groups mention is made of the relationships to other groups.



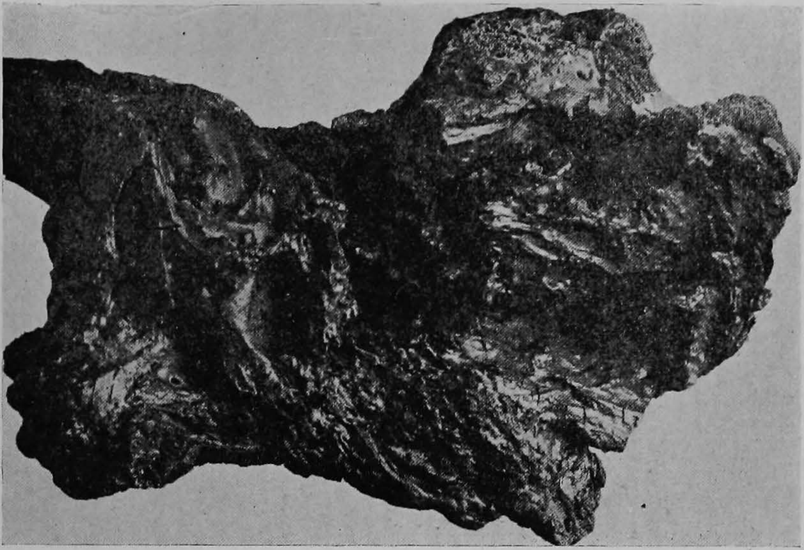
Volcanic ash

Tuff

Breccia
showing flow structure

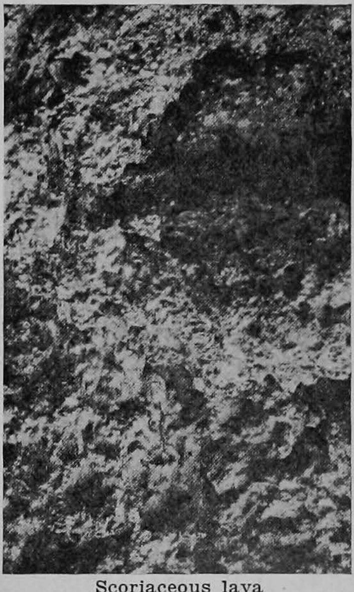
Breccia
showing flow structure

FORMS OF EXTRUSIVE VOLCANIC MATERIALS



Lava showing flow structure
Utah

Rhyolite
showing flow structure
Yellowstone Park



Scoriaceous lava

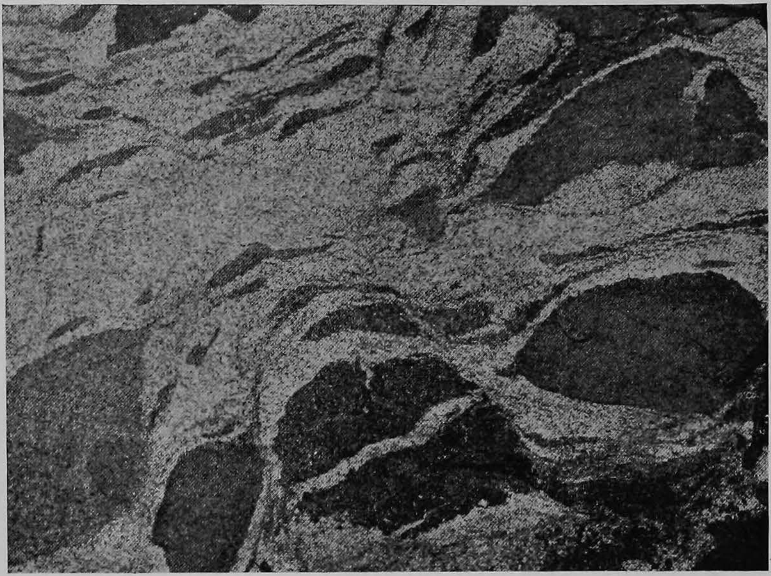
FORMS OF EXTRUSIVE VOLCANIC MATERIALS

CLASSIFICATION OF IGNEOUS ROCKS

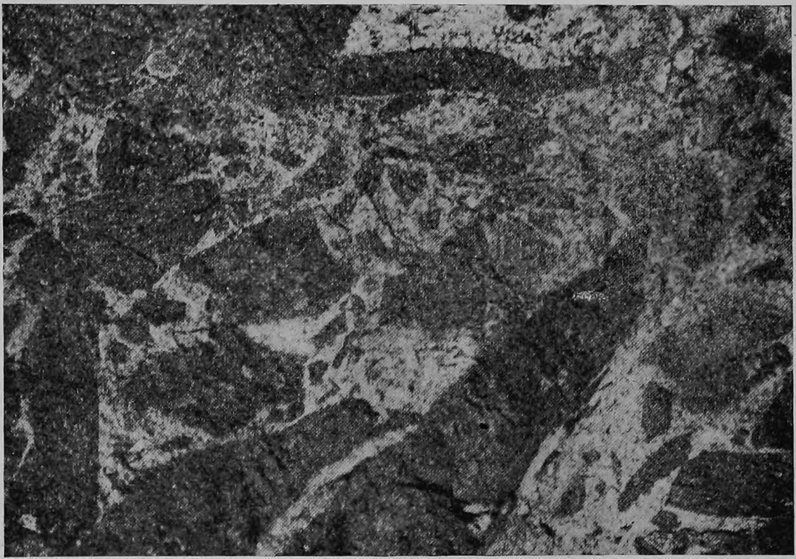
ROCK FAMILY	AVERAGE COMPOSITION	MINERAL COMPOSITION	GRANITOID GROUP	FELSITOID GROUP	GLASSY GROUP	FRAGMENTAL GROUP
GRANITE-RHYOLITE	*ACIDIC* SiO_2 70.0 Al_2O_3 15.0 Fe_2O_3.....+FeO 2.6 MgO 0.64 CaO 1.7 Na_2O 3.2 K_2O 4.0	*LIGHT-COLORED IN EXCESS* *Orthoclase, Quartz,* ± acid plagioclase, ± muscovite, (or, and) biotite, (or, and) hornblende	*Biotite granite* or *granitite* *Muscovite granite* *Hornblende granite* *Pegmatite* *Aplite*	*Rhyolite* *Rhyolite porphyry* *Granite porphyry* *Nevadite* *Quartz porphyry* *Granophyre* *Felsite*	*Obsidian* *Pitchstone* *Perlite* *Pumice* *Scoria*	*Rhyolite tuff* *Rhyolite breccia* *Rhyolite flow-breccia*
GRANODIORITE-DACITE	*ACIDIC* SiO_2 64.3 Al_2O_3 16.5 Fe_2O_3.....+FeO 4.7 MgO 2.1 CaO 4.4 Na_2O 3.6 K_2O 2.3	*LIGHT-COLORED IN EXCESS* *Acid plagioclase orthoclase, quartz, hornblende,* (and, or) *biotite,* ± augite	*Granodiorite* *Quartz diorite* *Quartz-mica diorite* *Monzonite* *Quartz monzonite* *Adamellite* *Tonalite* *Quartz diorite porphyry*	*Latite* *Quartz latite* *Dacite* *Quartz andesite* *Latite-phonolite* *Mica dacite* *Monzonite porphyry* *Dacite porphyry*	*Dacite-obsidian* (rare)	*Dacite tuff* *Dacite breccia*
DIORITE-ANDESITE	*INTERMEDIATE* SiO_2 59.0 Al_2O_3 17.0 Fe_2O_3.....+FeO 6.7 MgO 2.8 CaO 6.0 Na_2O 3.6 K_2O 2.2	*LIGHT AND DARK NEARLY EQUAL* *Plagioclase, hornblende,* or *biotite,* ± augite, ± orthoclase	*Diorite* *Mica Diorite* *Augite diorite* *Hornblende-mica diorite* *Gabbro-diorite*	*Andesite* *Hornblende andesite* *Mica andesite* *Pyroxene andesite* *Andesite porphyry* *Diorite porphyry*	*Andesite-obsidian*	*Andesite tuff* *Andesite breccia* *Andesite flow-breccia*
SYENITE-TRACHYTE	*INTERMEDIATE* SiO_2 60.8 Al_2O_3 17.2 Fe_2O_3.. ..+FeO 5.0 MgO 2.0 CaO 3.1 Na_2O 4.6 K_2O 4.9	*LIGHT-COLORED IN EXCESS* *Orthoclase* (sanidine), *hornblende, plagioclase,* ± biotite	*Hornblende syenite* *Mica Syenite* *Augite syenite*	*Trachyte* *Augite trachyte* *Hornblende trachyte* *Mica trachyte* *Trachyte porphyry* *Syenite porphyry* *Lamprophyre*	*Trachyte-obsidian* (very rare)	*Trachyte tuffs and breccias*

CLASSIFICATION OF IGNEOUS ROCKS—Concluded

NEPHELITE SYENITE-PHONOLITE	*INTERMEDIATE* SiO_2 55.1 Al_2O_3 20.3 Fe_2O_3.....+FeO 4.8 MgO 0.8 CaO 2.9 Na_2O 8.0 K_2O 5.8	*LIGHT-COLORED IN EXCESS* *Orthoclase, plagioclase nephelite, hornblende,* ± biotite ± sodalite ± leucite ± augite	*Nephelite syenite* *Litchfieldite* *Ditroite* *Sodalite syenite* *Leucite syenite*	*Phonolite* *Leucite phonolite*	*Phonolite-obsidian* (very rare)	*Phonolite tuffs and breccias*
GABBRO-BASALT	*BASIC* SiO_2 49.1 Al_2O_3 16.6 Fe_2O_3.....+FeO 10.8 MgO 6.2 CaO 9.2 Na_2O 3.1 K_2O 1.2	*DARK MINERALS IN EXCESS* *Augite olivine plagioclase,* biotite, hornblende	*Gabbro* *Olivine gabbro* *Hornblende gabbro* *Gabbro-diorite* *Hypersthene gabbro* *Norite* *Anorthosite* *Dolerite*	*Diabase* *Olivine diabase* *Basalt, Quartz basalt* *Mica basalt* *Olivine basalt* *Leucite basalt* *Nephelite basalt* *Melaphyre* *Basalt porphyry* *Gabbro porphyry*	*Tachylite*	*Basaltic tuffs and breccias* *Doleritic breccia*
PYROXENITE-PERIDOTITE	*BASIC* Pyr. Peri. SiO_2 50.5 38.0 Al_2O_3 4.2 8.0 FeO,Fe_2O_3 10.3 12.5 MgO 21.6 29.5 CaO 11.0 6.7 Na_2O & K_2O very low	*MINERALS ALL DARK* *Pyroxene* *olivine* *hornblende* *biotite* *magnetite*	*Peridotite* *Picrite* *Dunite* *Pyroxenite* *Hornblendite* *Serpentine rock*	*Limburgite*		



Intrusion breccia. Granite in schist
Rockwood, Colo.



Diorite gneiss boulders in matrix of granite. Formed by intrusion
Yosemite Valley, Calif.

FIELD AND GENERAL CLASSIFICATION OF IGNEOUS ROCKS

To anyone reasonably familiar with the rock-making minerals as they occur in the rocks, the classification of the members of the granitoid groups of the various families presents comparatively few difficulties. But the members of the felsitoid, glassy and fragmental groups of the different families are not easily distinguished even with a good lens. For this reason it has been found desirable to adopt a general classification suitable for field use, and for use where the microscope and chemical analyses are not available. But it is always desirable to use the regular classification when possible.

The following outline is a slightly modified form of a classification proposed in "Quantitative Classification of Igneous Rocks" (Cross, Iddings, Pirsson and Washington); elaborated by Pirsson in "Rocks and Rock Minerals;" and restated by Iddings in "Igneous Rocks," Volume I:

I. GRANITOID ROCKS (PHANERITES): All rocks whose mineral grains are large enough to be recognized by the unaided eye.

II. FELSITOID ROCKS (APHANITES): Rocks composed mainly or entirely of mineral grains so small that they cannot be seen and recognized without the aid of a strong lens. Here belong also porphyritic rocks having a felsitoid groundmass.

III. GLASSY ROCKS: Those composed so largely of glass that they have a vitreous luster.

IV. FRAGMENTAL ROCKS: Including chiefly tuffs and breccias. Rocks composed mainly of volcanic detritus, ranging in texture from dust grains to fragments several inches in diameter.

SUBDIVISION OF THE GROUPS

I. GRANITOID ROCKS (PHANERITES)

1. GRANITE: Chief minerals are FELDSPAR and QUARTZ. Subordinate minerals may include mica, hornblende, pyroxene. The group will include GRANITE, GRANODIORITE, QUARTZ DIORITE, QUARTZ MONZONITE. Granite porphyry may be included.

2. SYENITE: Chief mineral is FELDSPAR. Subordinate minerals may include quartz, mica, hornblende, pyroxene and nephelite. The group will include SYENITE, ANORTHOSITE, MONZONITE, FELDSPATHIC DIORITES and FELDSPATHIC GABBROS.

3. DIORITE: Chief mineral is HORNBLENDE. Subordinate minerals are mica, feldspar, pyroxene. The group will include DIORITES rich in the dark minerals, especially hornblende, and the HORNBLENDE GABBROS.

4. GABBRO: Chief mineral is PYROXENE. Subordinate minerals may be feldspar, hornblende, olivine and mica. The group will include mainly GABBROS and DOLERITES.

5. PERIDOTITE: OLIVINE is very abundant. Subordinate minerals may include pyroxene, hornblende, feldspar and mica.

6. PYROXENITE: PYROXENE makes up almost entire rock.

7. HORNBLENDITE: Rock is almost entirely HORNBLENDE.

II. FELSITOID ROCKS (APHANITES)

1. FELSITE: *All light-colored, felsitoid rocks, with few or no phenocrysts.* The colors may include white, gray, buff, yellowish-brown, pink and greenish. The group will include most of the non-porphyritic felsitoid rocks of the RHYOLITE group, many of the DACITES, QUARTZ ANDESITES and ANDESITES, most of the TRACHYTES, many LATITES and PHONOLITES.

2. FELSITE-PORPHYRY or LEUCOPHYRE: *All light-colored porphyritic felsitoid rocks,* no matter what the phenocrysts may be. The group will include most of the porphyritic members of the felsitoid groups of all the families, excepting the gabbro-basalt and the peridotite, pyroxenite, limburgite, augitite families. Whenever the phenocrysts are recognizable, the rock should be more definitely named, as QUARTZ PORPHYRY, QUARTZ FELSITE-PORPHYRY.

3. BASALT: *All dark-colored felsitoid rocks with few or no phenocrysts.* The colors may be dark gray, brown, dark green, black. The group will include chiefly BASALTS, DIABASES, DOLERITES, and the dark-colored rocks of the other felsitoid groups.

4. BASALT-PORPHYRY, or MELAPHYRE: *All dark-colored porphyritic rocks with felsitoid groundmass.* The group will include chiefly PORPHYRITIC BASALTS, DIABASES, DOLERITES, AUGITITES, MELAPHYRES, LAMPROPYRES, LIMBURGITES, and the dark-colored porphyritic rocks of the other felsitoid groups. Whenever the phenocrysts are recognizable, the rocks should be more definitely named, as OLIVINE BASALT PORPHYRY, and so on.

III. GLASSY ROCKS—THOSE COMPOSED OF GLASS OR HAVING A GLASSY LUSTER.

1. OBSIDIAN: *Non-porphyritic, glassy or vitreous rocks of any color.* The common colors are black, red, brown and greenish.

2. OBSIDIAN-PORPHYRY: *Porphyritic, glassy rocks of any color.* More definite names would be quartz obsidian porphyry, feldspar obsidian porphyry, etc.

3. PITCHSTONE: *Non-porphyritic rocks of any color, having a resinous or sub-vitreous luster.*

4. PITCHSTONE PORPHYRY: *Porphyritic rocks having a resinous or sub-vitreous luster.* More specific names would be quartz pitchstone porphyry, feldspar pitchstone porphyry, etc.

5. PERLITE: *Glassy rocks with perlitic structure.*

6. PUMICE: *Highly vesicular rock glass, usually very light-colored.*

VITROPHYRE is a general name for the porpyhritic glasses, as QUARTZ VITROPHYRE, FELDSPAR VITROPHYRE.

IV. TUFFS AND BRECCIAS (FRAGMENTAL)

These may be divided into FELSITE TUFF and FELSITE BRECCIA (light-colored), and BASALT TUFF, BASALT BRECCIA (dark-colored).

COLOR DIFFICULTIES

In some syenites, diorites and gabbros the feldspar is of a very dark gray to blackish gray color and, at first glance may be mistaken for hornblende or pyroxene. A very thin splinter or flake of the mineral will often decide the question. If the flake is gray or translucent, or both, it is reasonably certain that the mineral is feldspar. If a thin flake cannot be got, a small chip may be powdered under the hammer. A light colored powder generally indicates a feldspar. Bronzite and enstatite give light-colored powders, but the fibrous surfaces of these minerals, their peculiar submetallic luster and their tendency to break into fibers will distinguish them from the feldspars.

Greater difficulty will be experienced in deciding whether certain felsitoid rocks should be classed as *felsite* or *basalt; felsite porphyries* or *basalt porphyries.* Many rhyolites, dacites, andesites, latites, phonolies and trachytes are of light color and would readily be classed as *Felsites,* but occasionally these rocks are very dark gray, greenish gray, blackish gray to almost black. In cases of doubt the methods described above should be used. A hammer stroke on a thin edge of such a rock will generally produce a white to gray powder in spite of the dark color of the rock in mass. Thin flakes or slivers are commonly gray and often faintly translucent. The light-colored powder and the gray or translucent flakes result from the abundance of feldspar in the rock. On the other hand, the *Diabases* and *Basalts* with their abundance of dark minerals will yield dark powder, and the flakes will be dark and opaque.

SPECIFIC GRAVITY

The specific gravity of the compact *Diabases* and *Basalts* is noticeably greater than that of the *Felsites.* This will assist in classification.

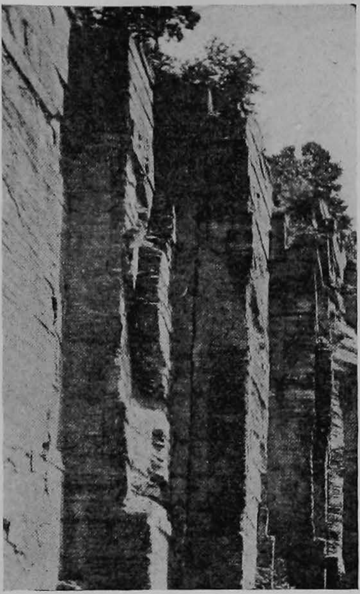
TOUGHNESS

The *Diabases* and *Basalts* are, as a rule, tougher and break less easily than the *Felsites,* and the fracture surface is commonly not so smooth and regular as in the *Felsites.*

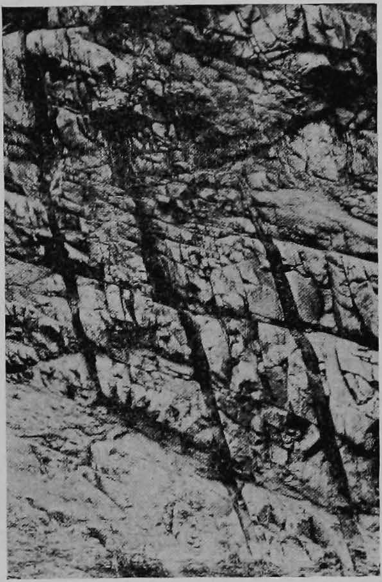
STRUCTURES

Under the term "structure" are included the larger features of rocks, such as the massive structure, jointing, parting, sundering, columnar structure, vesicular structure, amygdaloidal structure, and others. Sedimentary rocks are divided into depositional beds or strata, and are said to be stratified. The absence of this feature in igneous rocks has led to the use of the contrasting terms UNSTRATIFIED and MASSIVE in describing igneous rocks.

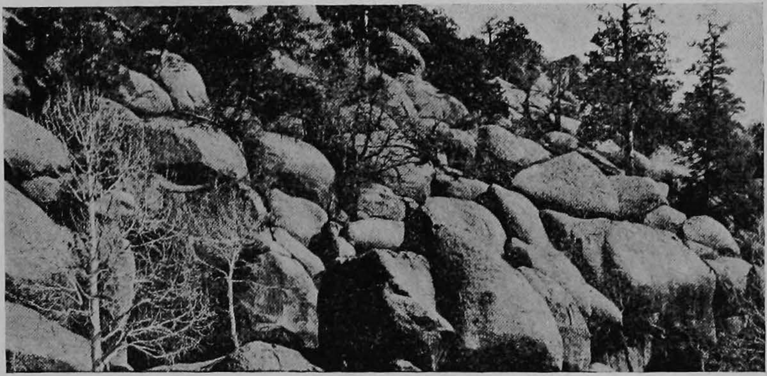
JOINTING is the division of a rock mass into blocks more or less regular, by two, three or more sets of intersecting fissures or cracks. The causes of jointing are many and complex, but tension, compression, torsion and shearing are the most important. Tension, or the pulling stress, and compression are developed in practically every form of crustal movement, and it is probable that earth movements are responsible for a very large part of the jointing of igneous rocks. As solid rock occupies less space than the molten mass from which it was formed, it is evident that tension results from the contraction consequent upon cooling. This form of tension jointing is well illustrated by the columnar jointing of basalts and other rocks. In the case of a dike or an intruded sheet, the surface in contact with the solid rock cools rapidly, and contraction causes tension stresses about certain points. As the lava is homogeneous, and cooling is uniform throughout the contact surface, these stress points are likely to be rather regularly spaced. The smallest num-



Jointing in shale



Jointing in granite
Grand Canyon, Arizona

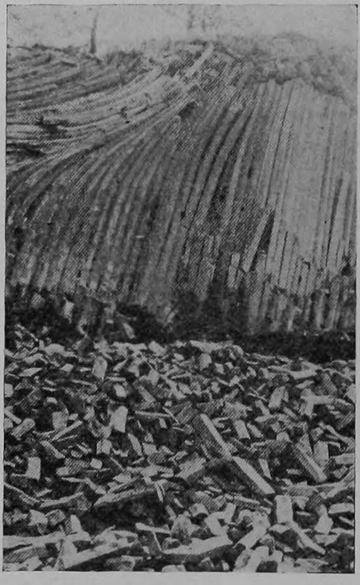


Jointed and weathered blocks of granite

ROCK STRUCTURES

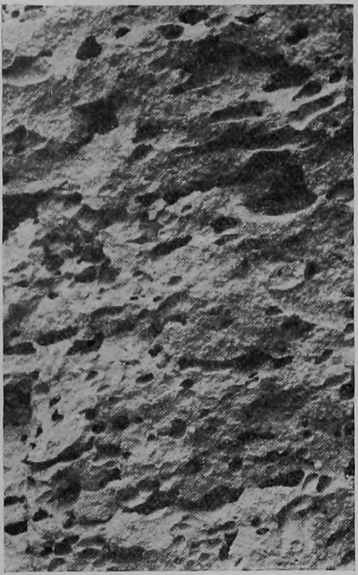
Weathering of a sandstone along joint planes

Spheroidal sundering

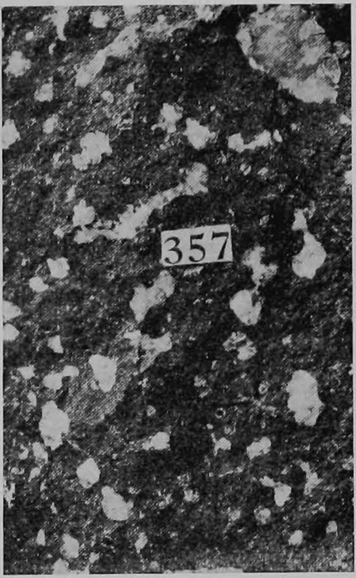


Columnar jointing in basalt

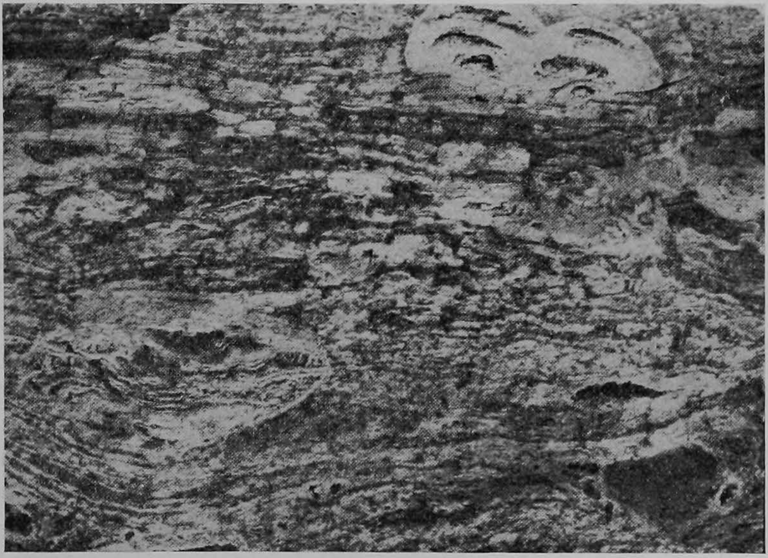
ROCK STRUCTURES



Vesicular structure in basalt



Amygdaloidal structure in basalt



Flow structure and lithophysae in rhyolite

ROCK STRUCTURES

ber of radiating fractures which will relieve the stress in all directions about a point is three. As the conditions are uniform, the radiating fractures are likely to be evenly spaced—120 degrees apart. Fractures from other centers must meet these, and hexagonal columns are formed.

The expansion and contraction of rock masses under the daily and seasonal changes of temperature are undoubtedly responsible for much minor jointing and fracturing, and for the development and opening-up of incipient fracturing or jointing. It is probable that much of the jointing shown in the outer parts of intruded bodies had its beginnings in the contraction accompanying cooling. Torsional or warping stresses accompany practically all crustal movements, and are probably important causes of jointing. Shearing movements develop parallel joints.

Occasionally one of the sets of fissures is so regular as to suggest stratification. When one set of joints divides the rock into thin plates, it is said to show platy parting.

SPHEROIDAL SUNDERING is the breaking down of blocks of rock by the separation of concentric layers from their surfaces.

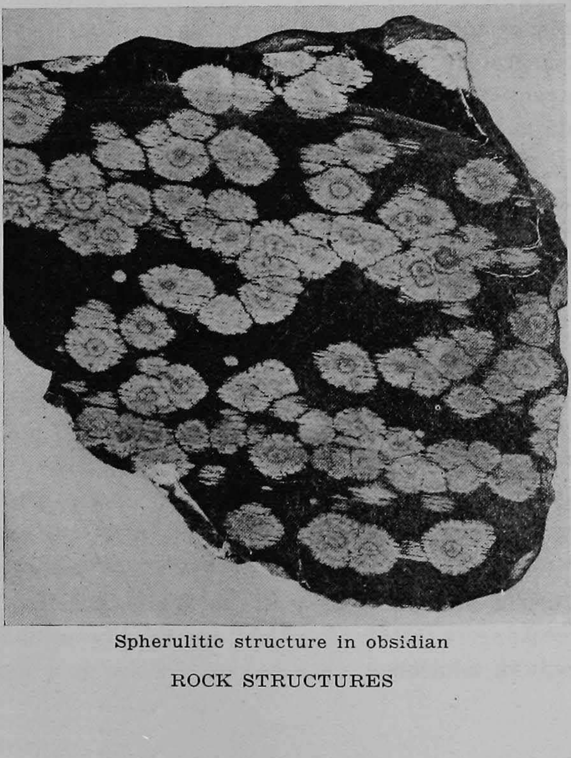
COLUMNAR STRUCTURE is the subdivision of a rock mass into more or less regular columns by jointing. This is common in basalt flows and dikes, but is also formed in other lavas and less frequently in coarse-textured rocks.

VESICULAR STRUCTURE: Molten rock commonly contains water and other vapors much condensed by pressure. When it rises to the surface and the pressure is relieved, these vapors expand and escape, leaving the rock open and porous. In basic rocks, such as basalt, the vesicles are commonly bubble-shaped and smooth-walled, while in the acid varieties the rapid discharge of the vapors may give the rock the appearance of solidified froth or foam (pumice). Explosive eruptions may convert such a viscous, spongy mass into angular fragments, ash or dust.

AMYGDALOIDAL STRUCTURE: Water charged with mineral matter circulating through a vesicular rock may deposit its load in the vesicles and gradually fill them. The mineral masses filling the cavities are called amygdules, and the rock is said to be amygdaloidal.

FLOW STRUCTURE is a more or less regular, wavy banding, due to movement while the rock was in a plastic or viscous condition. It is most common in acid lavas, such as rhyolite, but

Perlitic structure



Spherulitic structure in obsidian

ROCK STRUCTURES

occurs also in obsidian, pitchstone, andesite, trachyte, phonolite, pumice, and occasionally in the felsitoid rocks, such as granites and gabbros. In the rhyolites glassy bands frequently alternate with bands much more completely crystallized. The minerals are commonly arranged with their longer dimensions parallel with the direction of flow. Occasionally similar banding shows a predominance of a certain mineral in one band and another mineral in the next.

THE SPHERULITIC STRUCTURE is somewhat common in the acid lavas. Spherulites are generally of globular form, and consist mainly of extremely fine needles of feldspar radiating from their centers. Other minerals, such as tridymite (a form of silica) and quartz, are generally present. The spherulites range in diameter from a small fraction of an inch to several inches, and are generally arranged along flow lines in the lava.

WEATHERING

All rocks exposed at the surface of the earth are jointed or broken into blocks, and these blocks are cut by many subordinate joints or fractures. Most of the rock-making minerals have cleavage planes, along which they split easily when subjected to strain. The expansion and contraction of rocks, resulting from rise and fall of temperature from midnight to mid-day, and from season to season, cause strains which produce myriads of minute fractures both within and between the mineral grains. Water enters the rock by these joints and minute fractures. In freezing, water expands with a force of about one ton per square inch. In cold climates the water entering these joints and fractures of rocks freezes and thaws, causing crumbling and further fracturing. The atmosphere contains oxygen, carbon dioxide and moisture—three very important agents of rock decay. These are always in contact with the surface of the rock, and the water which enters it carries oxygen and carbon dioxide far below the surface. Decaying plant matter on the surface also furnishes carbon dioxide and humus acid to the entering waters, and the roots of plants aid in mechanical disintegration.

The most important chemical changes in the weathering of rocks may be grouped under the headings: carbonation, oxidation, hydration and solution. But they seldom occur separately.

a. Carbon dioxide unites with certain elements of the rock, forming carbonates, most of which are readily soluble and are carried away in solution.

b. In the presence of moisture, oxygen unites with certain elements of the rocks, forming oxides, which are often carried away, or redeposited in and on the rock.

c. Water unites with the rock matter, forming hydrous secondary minerals which occupy more space than the original minerals, and so cause strain and fracture.

d. Water charged with carbon dioxide and with the carbonates formed is an active solvent for many rock substances.

It is evident that weathering includes both mechanical and chemical processes, and that each aids the other. Some minerals yield more readily to mechanical change, others to chemical change.

Quartz rarely shows evidence of chemical change, but the grains become broken and separated from the rock mass, and are carried by gravity and the aid of water to the streams. In their journey down the stream the smaller grains may be worn down to mud particles, while the larger may reach the sea as rounded sand grains.

The feldspars yield rather easily to both mechanical and chemical forces. Owing to their good cleavages, they break readily under strain, and frequently fall away into fine, sand-like grains before important chemical changes have taken place. The fine fracturing aids chemical action, and, as a consequence, feldspar grains do not travel very far toward the sea before they are reduced to mud or clay. Plagioclase appears to alter more readily than orthoclase, but the changes in the two minerals are quite similar. Water very soon causes hydration, and the carbon dioxide it carries attacks the potassium oxide of the orthoclase and microcline, and the sodium oxide and calcium oxide of the plagioclase, forming the carbonates of potassium, sodium and calcium which are carried away in solution. These alkaline carbonates increase the solvent power of the water, and it dissolves out a part of the silica of the feldspar. Water unites with aluminum and the remaining silica, forming a very stable end product, composed largely of kaolin. This whole process is known as kaolinization. Under certain conditions, bauxite and gibbsite—aluminum hydrates—are formed.

Another common chemical change in orthoclase, and to a limited extent in plagioclase, is the formation of sericite—a fine, silky, fibrous muscovite. This change also involves the loss of potassium and silica, and the addition of water. The silica may crystallize as quartz, or may pass away in solution. In the formation of sericite from plagioclase, the necessary potassium oxide comes in from potassium-bearing minerals—possibly orthoclase or microcline—and replaces the sodium and calcium oxides. The formation of sericite probably takes place at a considerable depth below the surface.

Plagioclases also alter into hydrous minerals called zeolites, and into zoisite, epidote, quartz and paragonite—a sodium mica similar to muscovite. The iron necessary for the epidote comes from other minerals.

The micas, on account of their softness and their perfect cleavages, yield readily to mechanical forces, and are soon broken up into scales and flakes. The cleavage planes afford good openings by which water enters mica-bearing rocks. Muscovite rarely shows much evidence of chemical change, and, next to quartz, is the most resistant of the important rock-making materials. Biotite and phlogopite alter easily. Their iron is changed to higher oxide and largely removed in solution. The potassium disappears in the form of a carbonate, and hydration changes the residue into chlorites (or vermiculites—minerals closely related to the chlorites). Epidote and quartz commonly accompany chlorite. The cleavage plates lose their luster, depth of color and elasticity, and crumble away. Kaolin results from the alteration of most of the aluminum-bearing silicates.

The microscope shows that magnetite is a common alteration product of biotite. The discoloration of biotite-bearing rocks is commonly due to the iron leached from the biotite.

The feldspathoid minerals weather very readily. Unaltered leucite is known only in recent lavas. In the older rocks it is found altered into a mixture of orthoclase and nephelite, orthoclase and kaolinite, orthoclase and muscovite, and into analcite. In these changes part of the potassium is probably carried away in solution as potassium carbonate. In the change to nephelite and analcite sodium must come in from other minerals.

The analcite breaks up into orthoclase and prehnite, and the orthoclase weathers into kaolin. Prehnite yields chlorite by the substitution of magnesium for calcium. Nephelite alters to zeolites, such as hydronephelite, natrolite and analcite, all of which yield kaolin as an end product. (Sodalite and cancrinite weather in practically the same way as nephelite.)

Epidote is a very stable mineral and rarely shows evidence of weathering, except by faded color and dimmed luster. But it probably alters to calcite, quartz, kaolin and iron oxides.

Garnets are also very stable, but they are known to alter into a great variety of minerals, of which talc, serpentine chlorite, iron oxides and epidote are the most important.

Olivine is one of the most unstable of the rock-making minerals. The most common alteration is to serpentine, which is ofter accompanied by quartz, magnesite and magnetite. These changes involve the hydration of the greater part of the magnesium, the separation of a part of the silica as quartz, the carbonation of a part of the magnesium and the higher oxidation of a part of the iron. Sometimes a part of the hydrated magnesium forms brucite. and a part may be both hydrated and carbonated into hydromagnesite. Opal may take the place of quartz. The final product is usually a clay, but this requires the addition of alumina from outside.

The amphiboles yield a variety of alteration products. Their good cleavage favors both mechanical and chemical disintegration. In the alteration of actinolite and tremolite the calcium and magnesium may be converted into carbonates and carried away in solution, or under favorable conditions they may be redeposited as calcite and dolomite. The magnesium sometimes unites with water and silica to form talc or serpentine. The iron is usually changed into a higher oxide and gives a red or brownish-red color to the residue. Occasionally magnetite is formed. The most important secondary mineral from hornblende is chlorite, but epidote, calcite, quartz, iron oxides and iron carbonate occur. The end product resulting from the complete decomposition of hornblende is a rusty-brown, sticky clay, rich in iron.

The pyroxenes are closely related to the amphiboles, and their modes of weathering and the secondary products are very similar. While hornblende occasionally changes to pyroxene, the change of augite to hornblende is very common. Actinolite and tremolite also form certain pyroxenes, and biotite forms from augite. The end product is similar to that derived from amphiboles.

GRANITE-RHYOLITE FAMILY

In this family are included all igneous rocks of the same general compositions as the granites proper. The family is divided into four groups:

A. The granites, granitoid.
B. The rhyolites, felsitoid.
C. The glasses, glassy texture and luster.
D. The tuffs and breccias, fragmental.

The first three groups are based mainly on the texture (size of grains) of the rocks, while the fourth group includes rocks composed mainly of fragmental material which belongs properly in this rock family.

Analyses of 360 specimens give the following average composition and range of composition for the family:

	Average Composition (per cent)	Range of Composition (per cent)
SiO_2	70.00	80.00 to 60.50
Al_2O_3	15.00	21.40 to 5.60
Fe_2O_3 FeO	2.60	9.80 to 0.00
MgO	0.64	2.90 to 0.00
CaO	1.70	5.40 to 0.00
Na_2O	3.20	6.20 to 0.15
K_2O	4.00	11.00 to 0.18

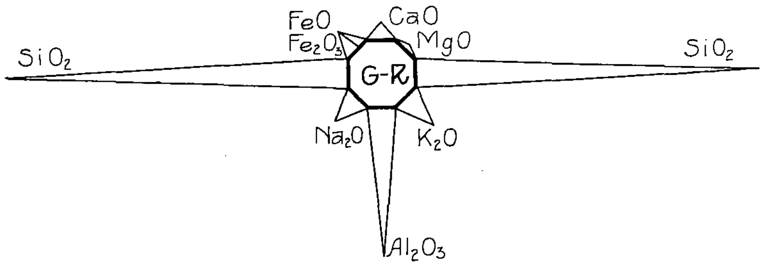


Fig. 48. Diagram to illustrate the average chemical composition of the granite-rhyolite family. The areas of the triangles are proportional to the percentages of the various oxides as shown in the average analysis above.

COLOR: The color of the granites proper depends mainly upon the color of the principal minerals. Red or flesh-colored feldspar gives a red color tone to the rock. White feldspar with black mica gives a gray or blue-gray color tone. The prevailing colors are red and gray, but pinkish-gray and almost white are not uncommon. The prevailing color tone of the rhyolites, rhyolite porphyries and granite porphyries is light, but various stains and weathering produce a variety of colors, such as buff, red, brown, and occasionally almost black. Obsidian is most commonly black, but brown, purple, green and red occur. Pitchstone ranges from black to brown, yellow and green. Pumice is commonly ash-colored to pale yellowish-gray. Perlite is commonly gray or bluish-gray to black. The color of the tuffs and breccias is much the same as that of the rhyolites, but the fragments may give the breccias a mottled appearance.

CRYSTALLIZATION: The granites, felsites, granite porphyries, many rhyolites and rhyolite porphyries are holocrystalline (completely crystalline), though in the finer-textured rocks the mineral grains may be too small to be distinguished without a microscope. Some rhyolites, rhyolite porphyries and related rocks consist of varying proportions of rock glass and mineral grains, while pitchstone, obsidian, perlite and pumice are composed almost entirely of rock glass. In the granites the mineral grains are mostly irregular in outline, and complete crystal boundaries are rare, though mica, hornblende and occasionally feldspar may show one or more crystal faces. The minor minerals —such as magnetite, zircon, garnet and apatite—are commonly in complete crystals, but they are generally too small to be seen without a good lens. In the porphyritic members the phenocrysts (porphyritic crystals) commonly have complete, or nearly complete, crystal boundaries, and the microscope may show many complete crystals in the groundmass.

TEXTURE: There is a wide range of texture from the pegmatites, whose mineral masses, or crystals, may reach a diameter of several inches, to obsidian, in which few or no mineral grains can be recognized. Pegmatite, graphic granite, and a few other granites are coarse-grained, while the majority of the granites are medium-grained. The aplites, the holocrystalline rhyolites, rhyolite porphyries, granite porphyries and felsites are felsitoid. In the glassy group come glassy rhyolites, glassy rhyolite porphyries, obsidian, pitchstone, perlite and pumice. The porphyritic texture occurs in the granites, but is not very common. It is characteristic of the rhyolite porphyries and granite porphyries, and is common in rhyolite, but less frequent in felsite, obsidian, pitchstone and perlite. In the finer-grained porphyritic rocks the phenocrysts often show rounded outlines, resulting from their partial solution by the molten mass in which they were formed.

MINERAL COMPOSITION: The members of the granite family vary widely in mineral composition, but quartz, orthoclase, plagioclase, microcline, biotite, muscovite, hornblende and pyroxene may be regarded as the chief minerals. Other minerals—such as magnetite, zircon and apatite—are almost always present in small, scattered crystals, and pyrite, titanite, ilmenite, garnet, tourmaline and fluorite are sometimes found. These are known as minor or accessory minerals.

THE FELDSPARS: They are by far the most important minerals of the granite-rhyolite family, frequently forming as much as 65 per cent of the volume of the holocrystalline rocks. They rarely show complete crystal outlines, except when they occur as phenocrysts. But tabular and brick-shaped crystals, or grains having two or more crystal faces, are not uncommon in the even-granular members of the family. Orthoclase is the most important of the feldspars occurring in the granite family. It is very commonly pink, but white and colorless crystals are not uncommon. Oligoclase is the chief plagioclase, but andesine is often found in the less acidic granites. The plagioclases are more commonly white, but pink and gray occur. Practically the only certain means of distinguishing plagioclase in the rock specimen is the twinning which is shown by fine parallel lines or striations on the basal cleavage faces.

Microcline resembles orthoclase in color and habit, and is rather common in pegmatites and granites.

QUARTZ rarely forms more than one-fifth the volume of a granite, and commonly less. It is generally in irregular, transparent, colorless grains, but as a phenocryst it commonly possesses crystal form, though the points and edges may be rounded by solution.

BIOTITE is by far the commoner of the micas, though it rarely equals the quartz in volume. When fresh, it consists of lustrous black or brownish-black, elastic plates or scales, sometimes showing an irregular hexagonal outline. Weathering gives it a rusty-greenish color.

MUSCOVITE may occur with or without biotite, but it is rarely an important constituent outside the even-granular members of the family. It occurs in thin, elastic, silvery-white, transparent scales, occasionally having a hexagonal outline.

HORNBLENDE is more common than muscovite, but much less common than biotite. It may occur as the only dark mineral, but is very frequently accompanied by biotite. It rarely shows perfect crystal outline, but often has two parallel faces. It is generally black or dark green, and usually shows good cleavage.

PYROXENE is not at all common in the granite family, but it is occasionally found in both the even-granular and the porphyritic members. The variety is usually ægirite or malacolite, but augite occurs. The grains are usually stouter than those of hornblende, are rarely so dark-colored or lustrous, and the cleavages are less perfect.

TRANSITIONS AND RELATIONSHIPS: Within the granite-rhyolite family there are both textural and mineralogical transitions from member to member and from group to group. Neglecting questions of origin and mode of occurrence, it is not easy to draw the line between very fine-grained granite and coarse-grained rhyolite; rhyolite and felsite; rhyolite and rhyolite porphyry; rhyolite porphyry and granite porphyry. Very glassy rhyolite grades into obsidian. By decrease of biotite, a biotite granite grades into a binary granite. By the addition of hornblende, a biotite granite becomes a hornblende-biotite granite, and by decrease of biotite this grades into hornblende granite.

By a decrease of quartz, the granites grade into the syenites. With an increase of hornblende (or biotite) and plagioclase, and a decrease in quartz and orthoclase, they grade into diorites. By a decrease in quartz and an increase in plagioclase, the granites grade into the granodiorites and quartz diorites. Similar transitions exist between the rhyolites and trachytes, the rhyolites and andesites, and other groups.

OCCURRENCE: The granite-rhyolite family is the most important and widely distributed of the igneous rocks. The granites are intrusive and occur in almost all the various forms of intrusive bodies, but stocks and batholiths are especially common.

In Colorado they occupy large areas in practically all the ranges.

Rhyolites occur both as extrusive and intrusive rocks. Dikes and sheets are the commonest intrusive forms, while flows are the characteristic extrusive bodies. Rhyolitic rocks are especially abundant in the San Juan and Leadville regions, but they are found almost everywhere throughout the mountain area.

Obsidian and pitchstone occur both intrusively and extrusively. They are found in comparatively small amounts in a number of localities in Colorado. Pitchstone (or obsidian) occurs in the Georgetown area, and at Silver Cliff. Obsidian is found on Engineer Mountain, in the Silverton area.

Perlite and pumice are extrusive. Pumice has been reported from near the head waters of Elk River

Rhyolite tuffs and breccias are extrusive, and are found in great abundance in Colorado, particularly along the Front Range and in the San Juan region. .

Strata of volcanic ash, probably of rhyolitic character, are found in the eastern part of the state, and in Huerfano County and near Durango. These are frequently referred to as pumice, and are commercially known by that name.

ECONOMIC: The granites are extensively used for building purposes, and are among the most durable of rocks. They weather slowly, but disintegrate readily in case of fire.

Rhyolite tuff is quite extensively used for building purposes in Colorado. Volcanic ash, under various names—''pumice,'' ''geyserite,'' ''silica,'' etc.—has been sold as an abrasive and polishing powder, and as an ingredient in mechanics' soaps.

FIELD AND GENERAL CLASSIFICATION OF THE ROCKS OF THE GRANITE-RHYOLITE FAMILY

Note.—In using the Field Classification it is desirable to be as exact and specific as possible. If a granite contains biotite or hornblende, the name should show that fact; thus Biotite Granite, Hornblende Granite. In such cases the simpler and more exact classifications will agree.

GRANITOID GROUP

GRANITE: *Biotite Granite, Granitite, Muscovite Granite, Muscovite-biotite Granite, Hornblende Granite, Hornblende-biotite Granite, Binary Granite, Alaskite, Aplite, Pegmatite, Graphic Granite, Greisen, Pyroxene Granite.*

FELSITOID GROUP

PORPHYRITIC GRANITE: *Porphyritic Granite.*

FELSITE: *Rhyolite, Aporhyolite, Liparite, Felsite, Lithoidite.*

FELSITE PORPHYRY OR LEUCOPHYRE: *Rhyolite Porphyry, Granite Porphyry, Nevadite, Quartz Porphyry, Granophyre, Microgranite, Tordillite* or *Alaskite Porphyry.*

GLASSY GROUP

OBSIDIAN: *Obsidian.*

OBSIDIAN PORPHYRY or VITROPHYRE: *Obsidian Porphyry*

PITCHSTONE PORPHYRY: *Pitchstone Porphyry* or *Vitrophyre.*

PERLITE: *Perlite.*

PUMICE: *Pumice.*

FRAGMENTAL GROUP

FELSITE TUFF: *Rhyolite Tuff.*

FELSITE BRECCIA: *Rhyolite Breccia.*

A. THE GRANITE GROUP, GRANITOID

BIOTITE GRANITE OR GRANITITE is the commonest of the granites and consists of orthoclase quartz and biotite, with more or less plagioclase (albite, oligoclase and andesine). Magnetite, apatite and zircon are usually present in small amounts, but are seldom readily visible without a lens.

MUSCOVITE GRANITE is similar to biotite granite, but contains muscovite instead of biotite. It is usually richer in quartz and poorer in plagioclase than biotite granite.

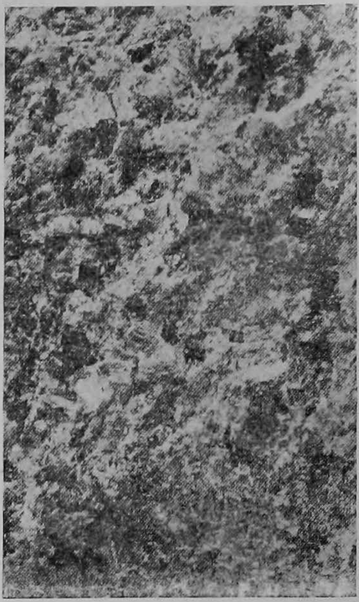
Muscovite-Biotite Granite contains the two micas in about equal amount. (This is sometimes called "granite proper," "two-mica-granite," "binary granite" and "granulite." But these names are not in general use, and the last two are used for other rocks.)

HORNBLENDE GRANITE contains hornblende instead of mica. The proportions of quartz and orthoclase are usually smaller, while that of plagioclase is commonly greater. (Some authors give this name to a granite containing both hornblende and biotite.)

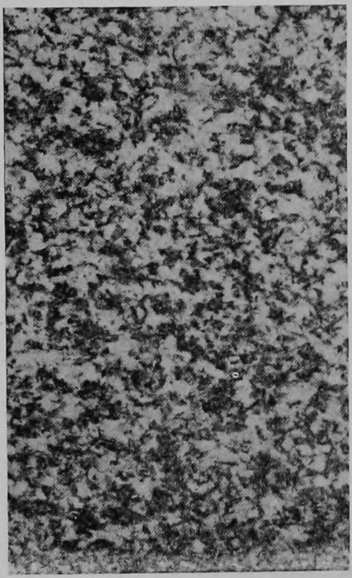
Hornblende-Biotite Granite contains both hornblende and biotite, but is otherwise like hornblende granite. It is sometimes called hornblende granitite.

Binary Granite is a name commonly applied to granites consisting almost entirely of quartz and alkali feldspar.

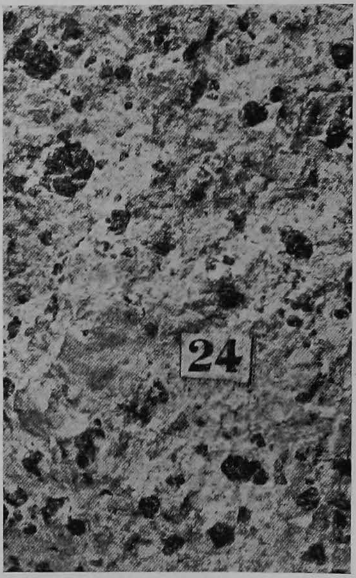
Pegmatite



Hornblende granite

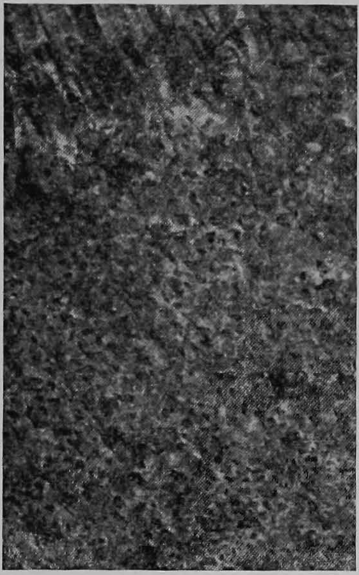


Biotite granite
Barre, Vt.



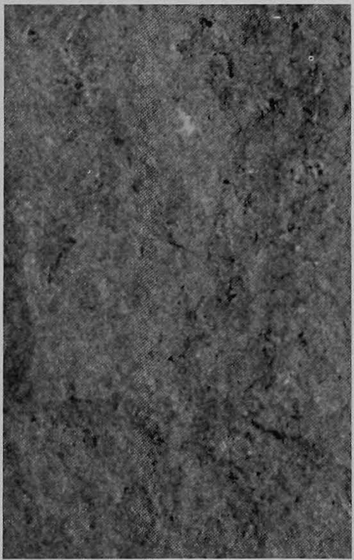
Granite porphyry
(Nevadite)
Eagle Co., Colo.

GRANITE-RHYOLITE FAMILY

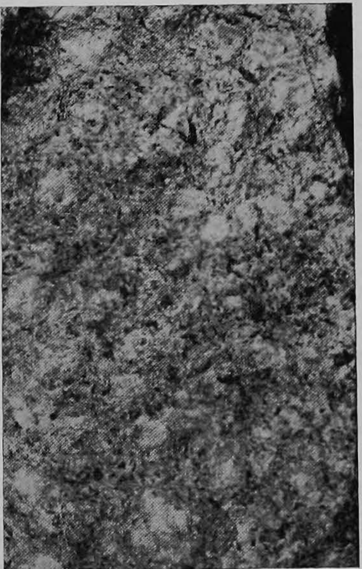


Graphic granite
(transverse section)

Graphic granite
(longitudinal section)



Rhyolite



Rhyolite porphyry

GRANITE-RHYOLITE FAMILY

Alaskite is composed essentially of quartz and alkali feldspar (orthoclase and albite).

Aplite (granitic) is a granite of fine, sugary texture, containing little or no muscovite or dark mineral, and occurring mainly in narrow dikes or veins cutting other granitic rocks. The mineral grains commonly have crystal boundaries. (The name "binary granite" is sometimes applied to muscovite-biotite granite.)

PEGMATITE consists mainly of microcline or orthoclase, quartz and muscovite. Biotite is rare. The texture is very coarse, and much of the feldspar and muscovite of commerce come from pegmatite. It is a dike rock or vein rock occurring very commonly in the areas of ancient granitic rocks, such as those forming the cores of many mountain ranges.

Graphic Granite is a special form of pegmatite in which the quartz occurs in long, parallel columns inclosed in the feldspar. When the rock is broken at right angles to the quartz columns, the cross-sections of the columns and their arrangement suggest Hebrew letters. (Hence the name "graphic granite"; Greek *grapho,* "I write.") Rare minerals—such as tourmaline, beryl and garnets—are frequently found in pegmatite.

Greisen consists of quartz and a white or gray or greenish-gray mica which usually carries lithium. Tin ore (cassiterite) is commonly associated with greisen. Fluorite, topaz and tourmaline are sometimes quite abundant. Greisen proper is granite in which the feldspars have been replaced by mica and quartz through the agency of vapors accompanying or following igneous intrusion.

Pyroxene Granites are comparatively rare. They are usually poorer in quartz and orthoclase, and richer in plagioclase, than most of the granites. Biotite or hornblende, or both, may accompany the pyroxene in variable amounts. The pyroxene may be augite (augite granite); or ægirite (ekerite and rockallite); or hypersthene (charnokite); or enstatite, etc.

The porphyritic texture occurs in a number of granites. The commonest phenocryst is feldspar.

B. THE RHYOLITE GROUP, FELSITOID

The rocks in this group have essentially the same chemical composition as the granite (granitoid) group. The minerals are mainly feldspar and quartz, but biotite, pyroxene and hornblende are frequently present. Magnetite, apatite and zircon are the commonest minor minerals, and occur in minute crystals. The porphyritic texture is common, and quartz, orthoclase, plagioclase, and occasionally biotite, hornblende and pyroxene, occur as phenocrysts.

Texturally the non-porphyritic and the groundmass of the porphyritic members of the group are composed mainly of mineral grains too small to be recognized by the unaided eye. The lens brings out the fact that the rock is for the most part granular. Glassy or uncrystallized matter may be present, but not in sufficient amount to give the rock a glassy luster.

The vesicular and the spherulitic structures are common in glassy rhyolites, but not so common in the felsitoid rhyolites. The amygdaloidal structure occurs, but is not common. Flow structure is more common in the rhyolites and the glasses of the granite family than in the corresponding group of other families. The alternating bands commonly differ markedly in texture—glassy bands alternating with finer granular.

RHYOLITE is the general name for the group, which includes rocks composed chiefly of quartz, orthoclase and albite, with small but varying amounts of biotite, pyroxene and hornblende. The phenocrysts of the porphyritic rocks are commonly quartz, orthoclase or sanidine, but albite and the dark minerals occur.

RHYOLITE PORPHYRY is a rhyolite in which phenocrysts make up a very considerable proportion of the rock.

Aporhyolite is a name applied to rhyolites which were once glassy, but have become largely or wholly crystalline by a form of metamorphism, called devitrification.

Liparite is another name for rhyolite.

GRANITE PORPHYRY is a rock in which the phenocrysts are so numerous as to give it the general appearance of a granite. The groundmass varies in texture and may grade into the granitoid. The rock then forms a connecting link between the rhyolites and granites.

NEVADITE is a granite porphyry.

QUARTZ PORPHYRY as now understood is a dike or sheet rock consisting of a dense groundmass carrying phenocrysts of quartz. When feldspar phenocrysts are present also, it is called a QUARTZ-FELDSPAR PORPHYRY. There is no essential difference between these and rhyolite porphyry.

GRANOPHYRE is a quartz porphyry in which the minerals of the groundmass are intergrown in much the same way as are the quartz and feldspar of graphic granite. This intergrowth can rarely be detected with a lens.

Microgranite is essentially a quartz porphyry with a very dense (fine-grained) groundmass.

FELSITE is a non-porphyritic rock of very fine granular texture (lithoidal), consisting mainly of quartz and alkali feldspar. Glass may be present in small amounts. The name "felsite" is now used in a much wider sense, as indicated in the Field and General Classification of Igneous Rocks, page 305.

Lithoidite is a textural term applied to rhyolites having a very fine-grained, non-vitreous groundmass and a dull, stony luster. They may be porphyritic.

Tordrillite, Alaskite Porphyry, is a rhyolite composed almost entirely of quartz and alkali feldspar. The phenocrysts may include orthoclase, plagioclase, quartz and mica. It occurs in the Georgetown, Aspen and Boulder areas. It corresponds to alaskite in the granite group.

To the rhyolite group belong, wholly or in part: *Ailsyte, Comendite, Felsophyre, Grorudite, Quartz Tinguaite, Keratophyre, Paisanite, Pantellerite, Quartz Keratophyre, Quartz Bostonite, Quartz Porphyrite,* and others.

C. THE GLASS GROUP—GLASSY TEXTURE AND LUSTER

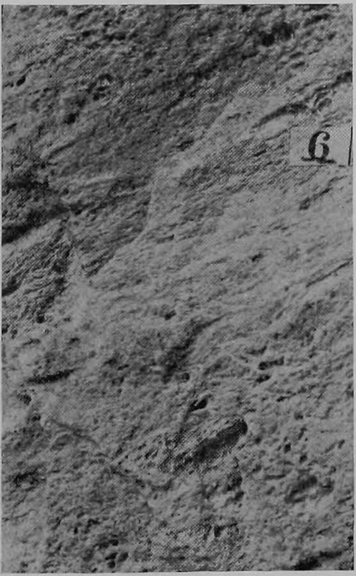
OBSIDIAN (rhyolite glass) is a volcanic glass having approximately the chemical composition of granite. It is sometimes sparingly porphyritic, with the phenocrysts arranged along flow lines. A banded appearance occasionally results from the presence of clouds of minute crystals, or spherulites, or stone bubbles (lithophysæ), arranged along flow lines. The color ranges from black to brown, purple and red. It breaks with a smooth conchoidal fracture, and thin splinters are translucent or transparent. It occurs as sheets and dikes, and as glassy surfaces over rhyolite or related lavas. In some cases the central part of a dike may be partially or completely crystalline, while the borders are typical obsidian, as at Georgetown, Colorado.

The volcanic glasses of other rock families are called andesite-obsidian, trachyte-obsidian, etc.

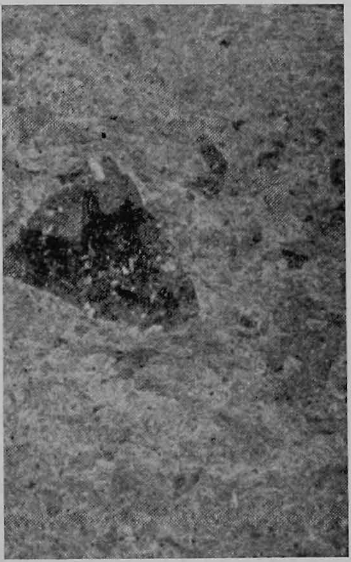
PITCHSTONE is very similar to obsidian, but has a dull, pitch-like or resinous luster. It is generally richer in minute crystals

Obsidian

Pumice



Rhyolite tuff



Rhyolite breccia

GRANITE-RHYOLITE FAMILY

and is more likely to be porphyritic than obsidian. The crystals commonly indicate a partial change from the glassy to the crystalline condition by devitrification. Pitchstone contains from 5 to 10 per cent of water. Pitchstones occur in other rock families.

PERLITE is a glassy rock more or less completely broken into globules somewhat resembling pearls, and made up of concentric shells. The structure is probably due to contraction at the time of cooling. A structure resembling the perlitic has been produced by rapid cooling. When the globules are crowded, they take on polygonal outlines. The rock is commonly of a gray color, and pearly or waxy luster.

PUMICE is a spongy, highly vesicular, or froth-like glass. The color varies from white to gray to yellowish or brownish. The luster is silky or glassy. It occurs as a froth-like surface over more dense rhyolitic lavas, or as the product of explosive eruptions. The structure is due to the escape of steam or other gas through the rock mass while it is still molten or viscous. Minute crystals are often abundant, and porphyritic texture occurs. Pumiceous structure occurs in the lavas of other rock families. The partially consolidated volcanic ash so common in Colorado, Nebraska and other states is often called pumice.

Uses: Pumice both in block form and as a powder is extensively used as an abrasive material, a filtering agent, a filler, and surfacer. Volcanic ash is used for scouring and cleansing purposes in such preparations as scouring soaps, powders, and pastes. It is used to a limited extent for covering and packing steam pipes and heat conduits.

SCORIA is a structural term applied to slag-like or cindery masses occurring on the surface of volcanic flows of any composition. Scoria frequently shows a ropy or twisted flow structure.

D. THE FRAGMENTAL GROUP

RHYOLITE TUFF is a rock formed of fine rhyolitic, volcanic detritus—such as dust, ash or sand—resulting from explosive volcanic eruptions by which lava is blown into fine fragments. It is usually grayish or whitish to buff or pale brown. The materials may fall on land and be carried to the sea by rivers, or they may fall on water and sink to the bottom. As a result, tuffs are frequently stratified and not uncommonly fossiliferous. Rhyolite tuffs occur in the San Juan, at Castle Rock, in Douglas County, and at many other points in the state. Tuffs occur in most of the rock families.

RHYOLITE BRECCIA is a rock composed of angular fragments, mainly of rhyolite bedded in finer material, like that of tuffs. The angular fragments may range in size from a fraction of an inch in diameter to a foot or more. Such breccias frequently contain fragments torn from the rocks through which the volcanic vent passes. They may be igneous, sedimentary or metamorphic.

When the fragments are of different color from the matrix or groundmass, the rock has a mottled appearance. Rhyolite breccias are abundant in the San Juan region.

RHYOLITE FLOW-BRECCIA is similar to rhyolite breccia, but the matrix or groundmass was molten when the fragments were caught up, and the rock reached its resting-place by flowing as a lava. Flow movement before solidification is frequently shown by the arrangement of the fragments or by banding.

GRANODIORITE-DACITE FAMILY, INCLUDING QUARTZ MONZONITE

The family is composed mainly of rocks which are intermediate in composition between the granites and the diorites, though some which suggest transitions to the syenites and gabbros are included. As in the granite family, there are four groups:

A. The granodiorite, quartz monzonite group, granitoid.

B. The dacite, quartz andesite, dellenite group, felsitoid.

C. The glasses, dacite-obsidian, etc., glassy group.

D. The tuffs and breccias group, fragmental.

Analyses of 102 specimens give the following average composition and range of composition for the family:

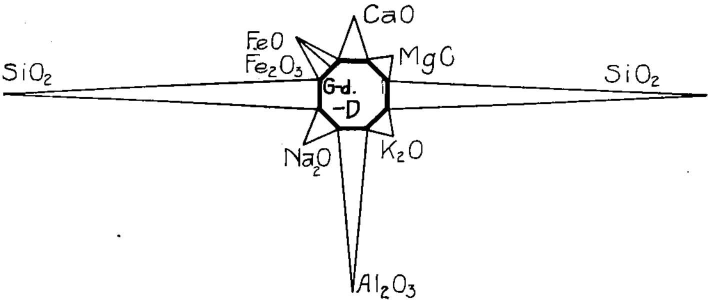


Fig. 49. Diagram to illustrate the average chemical composition of the rocks of the family.

	Average Composition (per cent)	Range of Composition (per cent)
SiO_2	64.27	75.71 to 52.03
Al_2O_3	16.42	23.44 to 12.58
Fe_2O_3	2.77	12.66 to 2.15
FeO	1.98	
MgO	2.12	11.69 to 0.13
CaO	4.40	8.50 to 0.35
Na_2O	3.57	4.91 to 0.15
K_2O	2.25	4.12 to 0.09

COLOR: The color depends upon the mineral composition. The rock-making minerals of this family are the same as those of the granite family, but the proportion of dark minerals is usually greater, though the light-colored minerals are commonly in excess of the dark. In general, these rocks are darker than those of the granite family, and a dark and light speckled appearance is common. The rocks of the felsitoid group are, as a rule, lighter-colored than those of the granitoid group. They vary from light gray to dark gray, and occasionally to almost black. Weathering causes lighter colors, such as yellowish gray, buff and brownish-pink. The glassy members are rare. The fragmental group resembles the felsitoid group in color, but the breccias are often mottled.

CRYSTALLIZATION: The granitoid rocks are holocrystalline. The felsitoid rocks are much more likely to be holocrystalline than those of the corresponding group in the granite family. Glass is, however, common in the groundmass, but is rarely present in large amount, and there are comparatively few rocks in the glassy group of this family. The porphyritic texture (fabric) is very common in the felsitoid group. The phenocrysts are chiefly plagioclase, quartz, sometimes orthoclase, and commonly one or more of the dark minerals, biotite, hornblende and pyroxene. In the granitoid group biotite and hornblende may have fairly complete crystal boundaries, and the feldspars may show one or more crystal faces.

TEXTURE: The range of texture is hardly so great as in the granite family. Rocks corresponding to the pegmatites in texture are very rare in this family. The medium grain is by far the commonest in the granitoid group.

MINERAL COMPOSITION: Quartz and orthoclase are much less abundant than in the granite family, while plagioclase and the dark minerals are relatively more important. The plagioclase includes albite, oligoclase, andesine and labradorite. Apatite, zircon, magnetite, titanite and other unimportant minerals are generally present, but are seldom visible even with a lens. The hornblende is the common dark-green to black variety, while the pyroxene may be augite or hypersthene.

TRANSITIONS AND RELATIONSHIPS: As in the granite family, textural transitions lead from one group to another, with no clearly drawn lines. By an increase of quartz and orthoclase the granodiorites and quartz diorites grade into the granites. By a decrease of quartz and orthoclase they approach the diorites, while an increase of pyroxene leads to the gabbros; a decrease of quartz and an increase of orthoclase, to the syenites. Similar transitions exist between dacites and quartz andesites, on the one hand, and trachytes, rhyolites and andesites, on the other.

OCCURRENCE: This family is of much less importance than the granite family, though in every part of the mountain region of the state detailed study of the geology is showing the existence of large areas occupied by monzonite and latite. They are almost all of comparatively recent geological age. Those of the San Juan are Tertiary, while those of the main mountain area are probably late Mesozoic. The modes of occurrence are the same as those of the granite family.

ECONOMIC: Very little use has been made of the rocks of this family.

FIELD AND GENERAL CLASSIFICATION OF THE ROCKS OF THE GRANODIORITE-DACITE FAMILY

Note.—In using the Field Classification it is desirable to be as exact as the texture and the minerals visibly present will permit.

GRANITOID GROUP

GRANITE: *Granodiorite, Quartz Diorite, Quartz-Mica Diorite, Quartz-Augite Diorite, Quartz Monzonite, Adamellite, Tonalite.*

PORPHYRITIC GRANITE: *Quartz Monzonite Porphyry, Quartz Diorite Porphyry.*

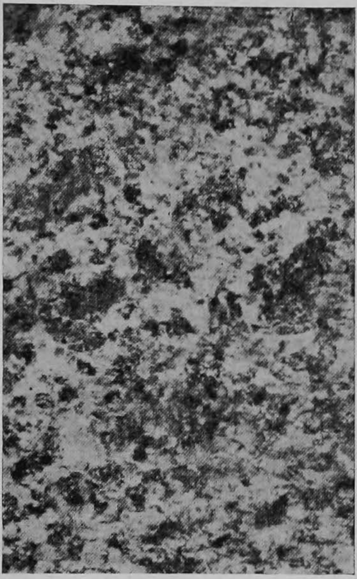
FELSITOID GROUP

FELSITE: *Dacite, Quartz Andesite, Dellenite, Mica Dacite, Biotite-Hornblende Dacite, Hornblende Dacite.*

FELSITE PORPHYRY: *Dacite Porphyry, Dellenite Porphyry.*

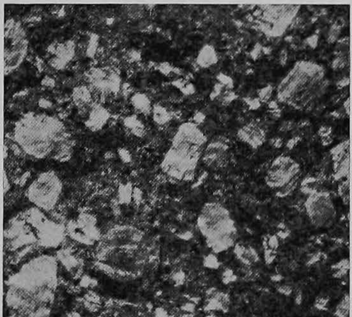
GLASSY GROUP

OBSIDIAN: *Dacite Obsidian, Volcanite.*
PITCHSTONE: *Dacite Pitchstone.*
PERLITE: *Dacite Perlite.*
PUMICE: *Dacite Pumice.*



Quartz monzonite
Chaffee Co., Colo.

Mica dacite
Boulder, Colo.



Dacite porphyry
Clear Creek, Calif.

Dacite flow breccia
Castle Mt., Mont.

GRANODIORITE-DACITE FAMILY

FRAGMENTAL GROUP

TUFF: *Dacite Tuff.*
BRECCIA: *Dacite Breccia.*

A. THE GRANODIORITE, QUARTZ MONZONITE GROUP, GRANITOID

GRANODIORITE (granite-diorite) is composed of plagioclase (andesine and [or] labradorite), a smaller amount of orthoclase, quartz, and commonly one or more of the dark minerals, biotite, hornblende and pyroxene.

QUARTZ DIORITE is similar to granodiorite, but the proportion of plagioclase is greater, while orthoclase may be absent or present in small amount. The rock generally contains one or more of the dark minerals, and the name is commonly given to that variety in which hornblende is the chief dark mineral. When biotite is the most important dark mineral, the rock is a QUARTZ-MICA DIORITE. When augite is abundant, the rock is called *Quartz-Augite Diorite.*

QUARTZ MONZONITE is very similar to granodiorite, but the proportion of orthoclase is greater. It is more closely related to granite.

QUARTZ MONZONITE PORPHYRY is a fine-textured quartz monzonite in which the phenocrysts are very numerous—equaling or exceeding the groundmass in amount.

Adamellite may be regarded as a quartz-hornblende-mica diorite, though the name is also used as equivalent to quartz monzonite.

Tonalite is a similar rock, with andesine as the chief feldspar.

QUARTZ DIORITE PORPHYRY is a fine-grained porphyritic rock of the quartz-diorite group in which the phenocrysts exceed the groundmass in amount. When the rock is very fine-grained (felsitoid), it should be placed in the quartz andesite-dacite group.

B. THE DACITE, QUARTZ ANDESITE, DELLENITE GROUP, FELSITOID.

DACITE is a rock composed mainly of fine grains of quartz, plagioclase and one or more of the ferromagnesian minerals: biotite, hornblende and pyroxene. Orthoclase (or sanidine) may be present in small amount, especially in the groundmass. In the porphyritic varieties plagioclase, quartz, orthoclase, biotite, hornblende and pyroxene may appear as phenocrysts, but the first two are commonest. When quartz is prominent as a phenocryst, the rock is easily mistaken for a quartz porphyry. The presence of striated feldspars in excess of non-striated would indicate a dacite. The groundmass often contains glass.

QUARTZ ANDESITE is essentially the same as dacite.

Dellenite may be classed as a dacite in which orthoclase is rather prominent and the ferromagnesian minerals are subordinate. It corresponds to quartz monzonite of the granitoid group.

MICA DACITE is one in which biotite is the important dark mineral.

Biotite-Hornblende Dacite, *Hornblende Dacite*, and other varieties are named according to the prominence of the dark minerals.

DACITE PORPHYRY and *Dellenite Porphyry* are varieties in which the phenocrysts are very abundant.

C. THE GLASSES (DACITE-OBSIDIAN, ETC.)—GLASSY GROUP

Glassy rocks are much less common in this family than in the granite family.

DACITE-OBSIDIAN is a rock glass having the composition of dacite.

VOLCANITE is a glassy rock of dacite composition, having phenocrysts of microcline, andesine, augite. It is very rare.

Dacite-Pitchstone, *Dacite-Pumice* and *Dacite-Perlite* are known, but are very rare.

D. THE DACITE TUFFS AND BRECCIAS (FRAGMENTAL) GROUP

DACITE TUFF is a rock formed of fine dacitic volcanic detritus such as dust, ashes, sand or fine fragments resulting from explosive volcanic eruptions by which lava is blown into fine fragments. The fresh rock is grayish to dark gray to brownish, but the altered rock is light gray to buff and pale brown. It closely resembles rhyolite tuff, and may be stratified by water action.

DACITE BRECCIA is a rock composed of angular fragments mainly of dacite bedded in finer material like that of tuffs.

THE DIORITE-ANDESITE FAMILY

To this family belong all igneous rocks having the same general chemical and mineral composition as the diorite group. As in the preceding family, there are four groups:

A. The diorites, granitoid.
B. The andesites, felsitoid.
C. The glasses, glassy texture and luster.
D. The tuffs and breccias, fragmental.

Analyses of 140 specimens give the following average composition and range of composition for the family:

	Average Composition (per cent)	Range of Composition (per cent)
SiO_2	59.89	65.94 to 45.11
Al_2O_3	16.78	25.54 to 12.15
Fe_2O_3	3.21	16.20 to 1.05
FeO	3.54	
CaO	6.04	11.68 to 2.59
MgO	2.78	11.70 to 0.40
Na_2O	3.59	8.49 to 1.19
K_2O	2.21	4.49 to 0.00

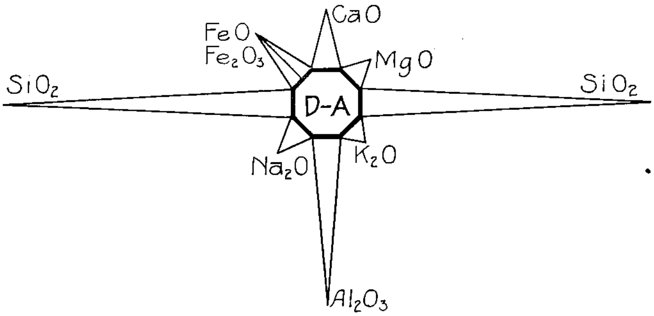


Fig. 50. Diagram to illustrate the average chemical composition of the rocks of this family.

COLOR: The diorites are composed of about equal amounts of light- and dark-colored minerals, and consequently present a speckled appearance. The prevailing color is gray—generally dark gray, and sometimes grayish-black. Weathering very commonly produces a greenish tone. The andesites vary from light gray to dark gray, and frequently show pinkish, yellowish and brown tints. The speckled effect is very common. Weathered andesites are very commonly light gray to buff and pinkish-buff. The glasses are similar in color to those of the granite family. The fragmental rocks are similar in color to those of the preceding families, but the speckled appearance is more common in the andesite tuffs and breccias.

CRYSTALLIZATION: The diorites and a very large proportion of the andesites are holocrystalline (completely crystalline). A more or less glassy groundmass is common in finer-grained andesites, but those having enough uncrystallized matter to give the rock a glassy luster are rare. The glassy group rarely forms any large rock masses, but andesite-obsidian, andesite-pitchstone, andesite-perlite and andesite-pumice are known. In these, minute crystals or microlites may form a large proportion of the mass. The porphyritic texture (or fabric) is common, and while plagioclase is the most abundant phenocryst, hornblende, biotite and pyroxene are common. They may be so numerous as to give the color value to the rock. The phenocrysts generally show complete crystal outlines, and the hornblende and biotite of the diorites frequently show two or more crystal lines.

TEXTURE: The textural range of the diorite-andesite family is large, but rocks corresponding to the pegmatite of the granite family are rare, and glasses are much less common than in that family. Andesites are very common rocks in America, and many of them are porphyritic. Diorites with phenocrysts of plagioclase and occasionally hornblende are not uncommon. Andesites are sometimes vesicular.

MINERAL COMPOSITION: Plagioclase (chiefly andesine, labradorite and oligoclase) is the most important mineral of the family. Orthoclase is rather rare, and marks transitions to the granodiorites and to the syenites. Hornblende is next in importance to plagioclase, but it may be largely or entirely replaced by biotite. Augite and other pyroxenes are frequently present, but rarely in large proportion. Magnetite, apatite, titanite and other minor minerals are almost always present, though rarely visible. Quartz is not rare in the groundmass of the andesites.

The plagioclase is often found in crystals large enough to show the striations (or twinning lines). Crystal boundaries are rarely perfect except in phenocrysts. The common color is milk-white, but glassy and gray feldspars are common. The hornblende is usually brownish-green to greenish-black. Complete crystal boundaries are very common in the andesites, but less so in the diorites. The cleavage is less perfect than that of biotite, but more perfect than that of pyroxene. The broad angle (124°) between the cleavage faces will help to distinguish it from pyroxene, whose cleavage faces meet at nearly a right angle. The biotite of the family is mostly black or very dark brown, and commonly shows crystal boundaries. The pyroxene may be augite, hypersthene, or rarely bronzite or enstatite. Olivine is of rare occurrence.

TRANSITIONS AND RELATIONSHIPS: By the increase of orthoclase and the decrease of plagioclase, the diorites grade into the syenites, and, with the addition of quartz, into granodiorites and granites. The increase of plagioclase (labradorite) to the practical exclusion of other minerals gives anorthosite, a variety of gabbro. When pyroxenes greatly increase, the diorites grade into gabbro. Similar transitions connect the andesites and trachytes, the andesites and dacites and rhyolites, the andesites and the basalts. There is a textural transition from the diorites to the andesites, and from these, by increase of glassy matter, to andesite-obsidian, andesite-perlite, etc.

OCCURRENCE: Diorites are not important in America, but andesites are very abundant, especially in the western mountain states. In Colorado diorites occur in the Rosita Hills, the Engineer Mountain area, and elsewhere. Andesites and andesite tuffs and breccias occupy large areas and form many lofty peaks in the San Juan region. They are also important in the Cripple Creek area, and at various places within the state andesite detritus forms a very large proportion of widely distributed sedimentary formations, such as the Denver. The andesites occur both as extrusive and intrusive rocks. Sheets and laccolithic bodies are very common. Monzonite and latite are common in the San Juan and along the Continental Divide in Chaffee, Gunnison, Boulder and other counties.

ECONOMIC: Practically no use is made of the rocks of this family, though diorite is occasionally marketed as granite.

ALTERATION: The andesites seem to decay very readily, if one may judge by the highly kaolinized rocks of this group so abundant in Colorado. The altered rocks vary in color from ash-gray to buff and rusty yellow and brown.

FIELD AND GENERAL CLASSIFICATION OF THE ROCKS OF THE DIORITE-ANDESITE FAMILY

Note.—The regular names of the members of the granitoid group should be used in the simpler classification if those names contain the group name. Thus: *Mica Diorite.*

A rock such as *Kersantite* may be called a *Mica Diorite,* or if the biotite forms phenocrysts, a *Porphyritic Mica Diorite.*

GRANITOID GROUP

DIORITE: *Diorite* or *Hornblende Diorite, Mica Diorite, Augite Diorite, Hornblende-Mica Diorite, Kersantite* when not porphyritic, *Gabbro-Diorite.*

PORPHYRITIC DIORITE: Any of the diorites may be porphyritic. *Camptonite* is commonly porphyritic.

SYENITE: Nearly all *Monzonites* are so rich in feldspar that they fall into the *Syenite* family. A few of the regular diorites are also rich in plagioclase, and in the Field Classification would find a place with the *Syenites.*

PORPHYRITIC SYENITE: *Porphyritic Monzonites* and *Porphyritic Diorites* rich in feldspar may be classed with the *Syenites.*

GRANITE: *Quartz Monzonite* and *Quartz Diorite* might contain enough quartz to justify placing them in the *Granite* group.

HORNBLENDITE: Hornblende-rich diorites may grade into *Hornblendites.*

FELSITOID GROUP

FELSITE: *Hornblende Andesite, Hornblende-Mica Andesite* or *Hornblende-biotite Andesite, Mica Andesite, Pyroxene Andesite, Augite Andesite, Hypersthene Andesite, Hornblende-Pyroxene Andesite, Latite, Latite-Phonolite, Propylite.*

FELSITE PORPHYRY: *Andesite Porphyry, Diorite Porphyry, Latite Porphyry, Monzonite Porphyry, Porphyrite.*

BASALT: Some *Andesites, Latites* and *Felsites* are very dark colored, and might appear to belong to the *Basalts.* In cases of doubt the tests suggested on page 307 should be applied.

GLASSY GROUP

OBSIDIAN: *Andesite-Obsidian.*

OBSIDIAN PORPHYRY: *Verite.*

PERLITE: *Andesite Perlite.*

PUMICE.

FRAGMENTAL GROUP

FELSITE TUFF: *Andesite Tuff.*
FELSITE BRECCIA: *Andesite Breccia.*

A. THE DIORITE GROUP, GRANITOID

DIORITE (or HORNBLENDE DIORITE): The typical diorite is a rock consisting mainly of plagioclase and hornblende. But small amounts of biotite, pyroxene and orthoclase give character to many diorites. Magnetite, apatite, titanite and zircon are commonly present, and occasionally in appreciable amounts.

MICA DIORITE is a diorite in which biotite is the most important dark mineral.

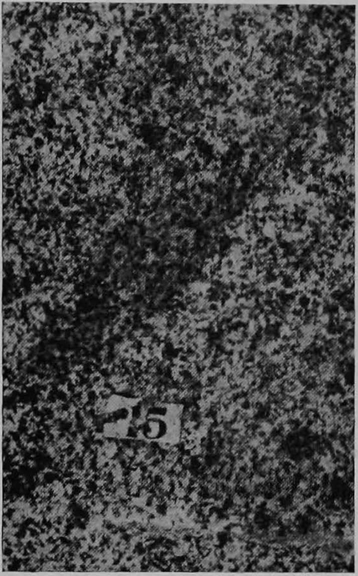
AUGITE DIORITE is a diorite in which augite is prominent, though hornblende may be the most important dark mineral.

HORNBLENDE-MICA DIORITE is a diorite in which hornblende and biotite are present in about equal amounts.

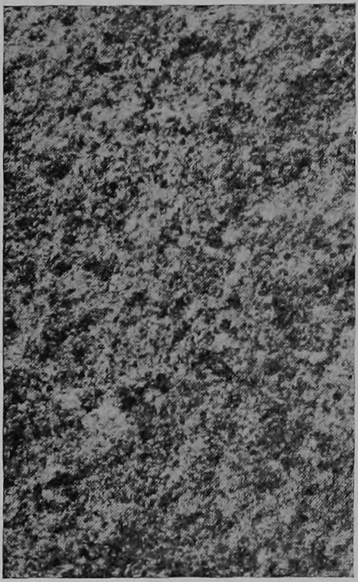
Kersantite contains both hornblende and biotite, and biotite sometimes occurs as phenocrysts. Orthoclase and pyroxene may be present.

MONZONITE is a rock composed mainly of plagioclase and orthoclase, and one or more of the dark minerals. The rock to which the name was first given is essentially an augite syenite in which orthoclase exceeds plagioclase in amount. At present the tendency is to apply the name to rocks in which plagioclase predominates and which are dioritic in type. The plagioclase is chiefly andesine or labradorite. The monzonites show great variety of composition, and they may be regarded as forming connecting links between the granodiorities and syenites, on the one hand, and the diorites and gabbros, on the other. When orthoclase exceeds plagioclase in amount, and the plagioclase is mainly andesine, the monzonite is syenitic in type. When plagioclase is decidedly in excess of orthoclase, the monzonite is dioritic in type. When pyroxene is abundant and the plagioclase tends toward labradorite, there is a transition to the gabbro group. When quartz is present and orthoclase equals or exceeds plagioclase, the rock is a quartz monzonite or a granodiorite. Varieties of monzonite are named according to the prominent dark mineral, as: hornblende monzonite, augite monzonite.

GABBRO-DIORITE is a rock intermediate between diorite and gabbro. It is possible that it is always derived from gabbro by the change of augite to hornblende.



Diorite



Diorite

Augite diorite
Germany

Monzonite
Silverton, Colo.

DIORITE-ANDESITE FAMILY

Camptonite is a dike rock consisting of plagioclase, hornblende, pyroxene, biotite and sometimes olivine; all of which may form phenocrysts. Glass may be present in the groundmass. The rock is usually close-grained, and might well be placed in the andesite group. Its appearance, and chemical and mineral composition, suggest basalt.

B. THE ANDESITE GROUP, FELSITOID

ANDESITE: The general name includes those felsitoid rocks having plagioclase as the most important mineral. Orthoclase is commonly absent, or present in very small amount. Hornblende, biotite, augite and hypersthene—one or more—are usually present and, according to their predominance, give names to the kinds of andesite. Olivine occurs, but is never prominent. Magnetite, apatite and other minor minerals are commonly present. The plagioclase includes andesine as the most important, and oligoclase and labradorite. One or more of the important minerals may form phenocrysts.

HORNBLENDE ANDESITE is an andesite in which hornblende is the most important dark mineral, though biotite and pyroxene may be present.

Hornblende-Mica Andesite (or hornblende-biotite andesite) is one in which both hornblende and biotite are prominent.

MICA ANDESITE has biotite as the most important dark mineral.

This variety ranges high in silica, and occasionally contains a noticeable amount of orthoclase. It grades toward dacite.

PYROXENE ANDESITE is one in which one of the pyroxenes—most commonly augite—is the prominent ferromagnesian mineral. This variety is usually low in silica, and grades toward the basalts. Olivine is more likely to occur in the pyroxene andesites than in the preceding varieties.

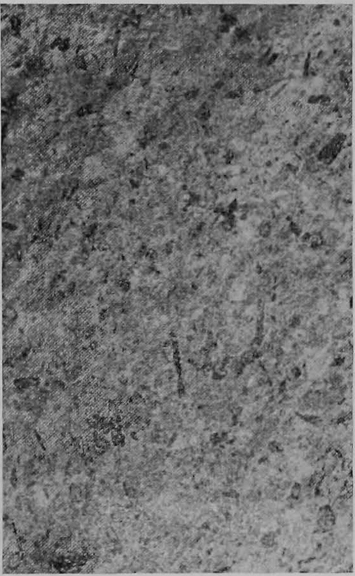
Augite Andesite is a pyroxene andesite in which augite is the prominent dark mineral.

Hypersthene Andesite is a pyroxene andesite in which hypersthene is prominent.

Hornblende-Pyroxene Andesite is one in which both hornblende and pyroxene are prominent.

ANDESITE PORPHYRY (or porphyrite) is essentially an andesite with porphyritic fabric. The varieties are named according to the phenocrysts.

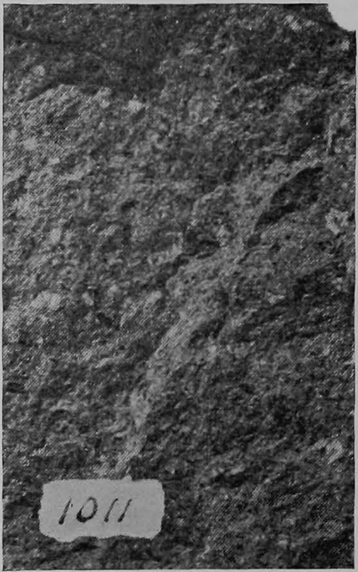
DIORITE PORPHYRY is a rock resembling andesite porphyry, but containing phenocrysts in excess of the groundmass. It may



Hornblende andesite

Porphyritic hornblende andesite

Hornblende-mica andesite
Eureka Co., Nev.



Andesite
Cripple Creek, Colo.

DIORITE-ANDESITE FAMILY

be regarded as forming a textural connecting link between the andesites and the diorites. The phenocrysts are of the same minerals as those of the andesites.

LATITE is a name given to the felsitoid rocks corresponding to the monzonites, and intermediate between trachytes and andesites. They are closely related to trachydolerite. Latite is composed of orthoclase, plagioclase, and subordinate amounts of one or more of the dark minerals: pyroxene, amphibole and biotite. Quartz may occur in small amount. The phenocrysts are plagioclase and the dark minerals.

LATITE-PHONOLITE is a rock intermediate in composition between latite and phonolite. The latite-phonolite of Cripple Creek is composed of orthoclase, plagioclases from albite to labradorite, rather abundant augite, the feldspathoid minerals; nosean, sodalite and analcite; and frequently hornblende and biotite. The feldspars and augite form phenocrysts.

MONZONITE PORPHYRY is a highly porphyritic rock of the monzonite type, but intermediate in texture between ordinary monzonite and latite. The phenocrysts may equal or exceed the groundmass in amount.

LATITE PORPHYRY is a richly porphyritic latite. The phenocrysts are chiefly plagioclase and the dark minerals.

Porphyrite is a name formerly applied to the more ancient (pre-Tertiary) porphyritic andesites. American geologists seem to be avoiding the use of the name.

Propylite is an andesite in which the original hornblende and pyroxene have been altered to chlorite or secondary hornblende.

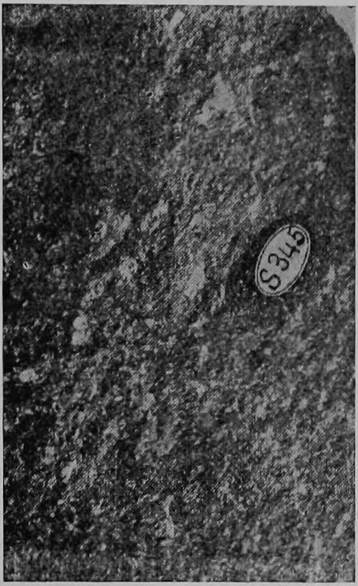
C. THE ANDESITIC GLASS GROUP

ANDESITE-OBSIDIAN, ANDESITE-PERLITE, ANDESITE-PITCHSTONE and ANDESITE-PUMICE are rare glassy rocks of this family. They have the same appearance as the corresponding rocks in the granite-rhyolite family. Phenocrysts of quartz and orthoclase may very rarely distinguish the glasses of the granite-rhyolite family, and phenocrysts of plagioclase those of the diorite-andesite family.

Verite is a glassy porphyritic andesite with phenocrysts of biotite and olivine.

D. THE ANDESITIC TUFFS AND BRECCIAS (FRAGMENTAL) GROUP

The tuffs and breccias of this family are not readily distinguished from those of the preceding families. The fragments of



Hornblende latite
Silverton, Colo.

Quartz latite
Silverton, Colo.

Andesite breccia
Cripple Creek, Colo.

Andesite tuff

DIORITE-ANDESITE FAMILY

andesite in the breccias may be large enough to show the characteristic speckled appearance of andesite. If the fragments are porphyritic, plagioclase phenocrysts may aid in identifying the rock.

THE SYENITE-TRACHYTE FAMILY, INCLUDING NEPHELITE SYENITES AND PHONOLITES

Syenite has been called quartzless granite. The term is inaccurate, but it suggests an important relationship in composition between the two groups.

The family may be divided into the usual four textural groups, but glasses are very rare, and tuffs and breccias are by no means common.

A. The syenites, granitoid.
B. The trachytes, felsitoid.
C. The glasses, glassy.
D. The tuffs and breccias, fragmental.

Analyses of 153 specimens give the following average composition and range of composition for the Syenite-Trachyte Division.

	Average Composition (per cent)	Range of Composition (per cent)
SiO_2	60.88	74.12 to 48.94
Al_2O_3	17.24	23.27 to 10.51
FeO Fe_2O_3	5.03	14.25 to 0.00
MgO	1.95	5.93 to 0.13
CaO	3.12	6.97 to 0.30
Na_2O	4.57	14.57 to 1.11
K_2O	4.86	11.67 to 0.34

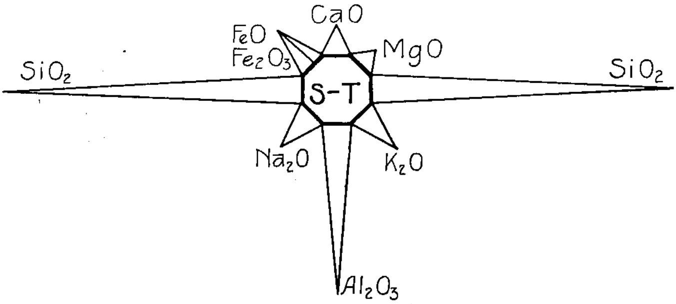


Fig. 51. Diagram to illustrate the average chemical composition of the rocks of the syenite-trachyte division of the family.

A comparison of the average composition of the syenite-trachyte family with that of the diorite-andesite shows a decrease in the iron oxides, magnesium oxide and calcium oxide, and an increase in the sodium and potassium oxides. These changes indicate a decrease in the ferromagnesian minerals and the lime-soda plagioclase, and an increase in the alkali feldspars (orthoclase and albite).

Compared with the average composition of the granite-rhyolite family, the larger percentage of iron oxides and magnesium oxide indicates a greater proportion of the ferromagnesian minerals, while the greater percentages of sodium oxide and potassium oxide indicate a larger proportion of the alkali feldspars.

COLOR: The light-colored minerals are in excess of the dark-colored, and as a consequence the general color is light. As in the granites, the feldspar is the dominant mineral, and in large measure controls the color. White feldspar and black or dark biotite or hornblende give a gray color, while pink feldspar and biotite or hornblende give a pink or gray-pink rock color. The trachytes are gray to dark-gray and buff to brownish-gray. The tuffs and breccias are of much the same color as those of the preceding families.

CRYSTALLIZATION: Holocrystalline rocks are the rule in this family, but trachytes, with a more or less glassy ground-mass, are known. Trachytic glasses are not common, but most of the types known in the granite-rhyolite family have their counterparts in the syenite-trachyte family. The porphyritic fabric is common in trachytes and phonolites. In the syenite group the order of crystallization is generally: hornblende, biotite, feldspar; and the completeness of the crystal boundaries follows the same order. The minor minerals are commonly in crystals.

TEXTURE: The syenite-trachyte family resembles the last two families.

MINERAL COMPOSITION: Orthoclase is the most important mineral, but microcline, sanidine, soda-orthoclase and albite may occur in considerable amounts. Oligoclase and andesine occur in those syenites closely related to the diorites and the gabbros. Muscovite occurs, but it is not common. Hornblende is the typical dark mineral, but biotite, augite and ægirite are common minerals in this family.

Lepidomelane, an iron-rich mica, may occur. Some rather rare syenites contain barkevikite, arfvedsonite and riebeckite. Quartz occurs, but it is not at all common. Olivine is rare. Iron oxides, titanite, apatite, zircon and other minor minerals are generally present.

The orthoclase may be pink or white, or colorless (sanidine), but the plagioclase is commonly white or gray. Except as phenocrysts, the feldspars rarely show complete crystal boundaries. The hornblende is very commonly green, and crystal boundaries are not uncommon even in the non-porphyritic rocks. The pyroxenes are usually green to brown, though they often appear greenish-black. The soda-rich pyroxenes ægirite (green) and acmite (brown) occur in the syenites having a large percentage of sodium oxide. The biotite is generally dark brown, and weathers to green.

TRANSITIONS AND RELATIONSHIPS: Within the family textural gradations connect the syenite, trachyte and glassy groups. The different varieties of syenites and trachytes grade into one another, and the family is naturally closely related to the nephelite syenite-phonolite division. The appearance of quartz shows a relationship to the granite-rhyolite family. Increasing plagioclase, hornblende and biotite mark a transition to the diorite-andesite family, while an increase of pyroxene and the appearance of olivine connect the syenite-trachyte family with the gabbro-basalt family.

OCCURRENCE: Syenite and trachyte occur in the Cripple Creek district and in Custer County. Trachyte is also quite abundant at several places in the state.

ECONOMIC: Syenite is used as a building stone in Arkansas, and the rock quarried near Salida and known as "Salida granite" is a syenite.

GRANITOID GROUP

SYENITE: *Hornblende Syenite, Mica Syenite, Augite Syenite, Quartz Syenite* if but very little quartz, *Syenite-Aplite, Syenite Pegmatite, Olivine Syenite, Monzonite, Nephelite Syenite, Zircon Syenite, Litchfieldite, Foyaite, Miascite, Laurdalite, Sodalite Syenite, Leucite Syenite.*

PORPHYRITIC SYENITE: *Porphyritic Syenite.*

GRANITE: *When quartz is prominent in Quartz Syenite* and *Monzonite,* the rocks may be placed in the *Granite Group.*

GABBRO: *Shonkinite* is sometimes so rich in pyroxene that it might properly be placed with the *Gabbro Group.*

FELSITOID GROUP

FELSITE: *Trachyte, Augite Trachyte, Hornblende Trachyte, Biotite Trachyte* or *Mica Trachyte, Aegirite Trachyte, Trachydo-*

lerite, Latites, Vulsinite, Phonolite, Leucite Phonolite, Latite Phonolite, Tinguaite, Orendite, Wyomingite.

FELSITE PORPHYRY: *Latite Porphyry, Monzonite Porphyry, Ciminite, Banakite.*

BASALT: Some *Latites* are very dark, but should be in the *Felsite Group. Lamprophyre* may be placed in the *Basalt* Group when very rich in the dark minerals. *Minette* is very rich in biotite and sometimes resembles *Basalt. Kersantite* and *Vogesite* are also very dark. The tests suggested on page 307 will commonly show that these rocks may be placed with the *Felsites.*

THE GLASSY GROUP

OBSIDIAN: *Trachyte-Obsidian, Hyalotrachyte, Phonolite-Obsidian.*

PITCHSTONE: *Trachyte-Pitchstone, Phonolite-Pitchstone.*

PERLITE: *Trachyte-Perlite.*

PUMICE: *Trachyte-Pumice, Leucite Phonolite-Pumice.*

PORPHYRIES: These rocks may occur in porphyritic forms.

FRAGMENTAL GROUP

FELSITE—TUFF: *Trachyte Tuff, Phonolite Tuff.*

FELSITE—BRECCIA: *Trachyte Breccia, Phonolite Breccia.*

FIELD AND GENERAL CLASSIFICATION OF THE ROCKS OF THE SYENITE-TRACHYTE FAMILY, INCLUDING NEPHELITE-SYENITES AND PHONOLITES

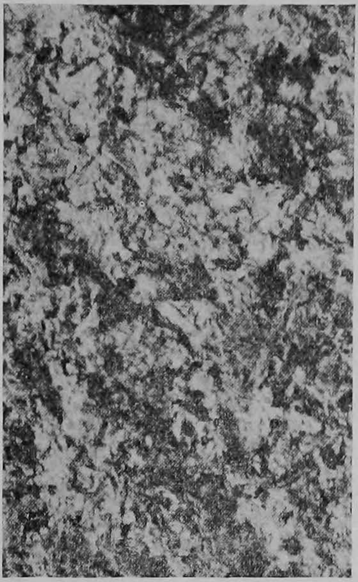
A. THE SYENITE GROUP, GRANITOID

HORNBLENDE SYENITE, or syenite proper, is composed largely of orthoclase, but oligoclase is commonly present. Hornblende is the prominent dark mineral, but biotite and augite frequently occur. Quartz sometimes appears in small amount. Titanite and other minor minerals are usually present.

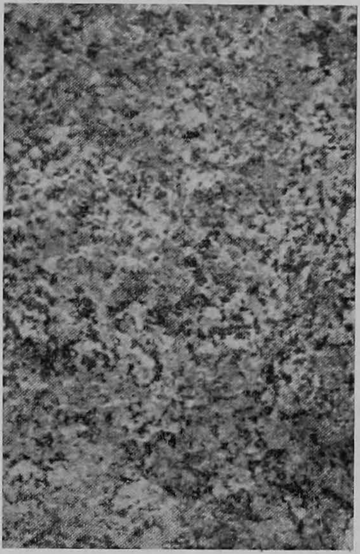
MICA SYENITE is like hornblende syenite, but biotite is the prominent dark mineral.

AUGITE SYENITE is one in which augite is the prominent dark mineral. Olivine is sometimes present.

Shonkinite is a basic syenite in which the feldspars are orthoclase and albite, but they are subordinate in amount to the dark minerals. Augite is sometimes the most important mineral. Biotite and olivine are commonly present. Nephelite and sodalite may be present.

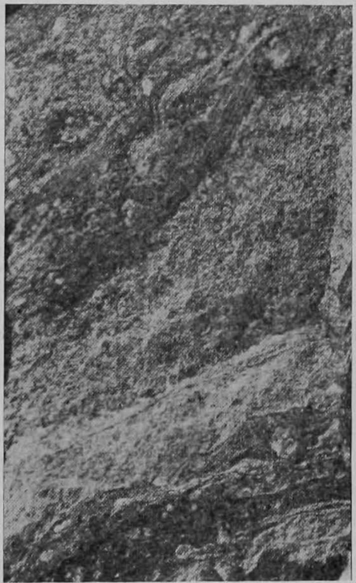


Syenite



Syenite

Trachyte



Trachyte
showing flow structure

SYENITE-TRACHYTE FAMILY

Quartz Syenite is one in which quartz is present, though in subordinate amount. It marks a transition to granite.

Syenite-Aplite is a fine-grained rock consisting of orthoclase, and albite with subordinate amounts of soda-bearing pyroxene (ægirite) and (or) soda-bearing amphibole (arfvedsonite or riebeckite).

Syenite-Pegmatite is a very coarse-textured syenite generally containing muscovite, and sometimes corundum. A syenite-pegmatite is the source of the corundum of Ontario.

Olivine Syenite is a syenite containing an appreciable amount of olivine. The olivine syenite of Cripple Creek contains intergrown orthoclase and albite, a little quartz, pyroxene, olivine and the common minor minerals.

Porphyritic Syenite is a syenite carrying phenocrysts—usually feldspar.

MONZONITE (syenite type) is a rock composed of orthoclase and plagioclase in about equal amounts, together with one or more of the dark minerals. (See fuller discussion of monzonite under Diorite-Andesite Family.)

B. THE TRACHYTE GROUP, FELSITOID

TRACHYTE is a general name for the felsitoid rocks corresponding to the syenites. The chief feldspar is orthoclase (sanidine), but soda-microcline, albite and oligoclase occur. Mica, amphibole, pyroxene and olivine are common, and varieties of trachyte are named according to the prominence of these dark minerals.

AUGITE TRACHYTE is one in which augite is the most important dark mineral. Sanidine is frequently the most important feldspar.

HORNBLENDE TRACHYTE is one in which hornblende is the chief dark mineral.

MICA TRACHYTE, or *Biotite Trachyte* has biotite as the most important ferromagnesian mineral.

Ægirite Trachyte has ægirite as the pyroxene. Other trachytes have the soda-bearing amphiboles (arfvedsonite and riebeckite) as the principal dark minerals, and are named accordingly.

TRACHYTE PORPHYRY is a richly porphyritic trachyte. The phenocrysts are principally orthoclase or sanidine, but the dark minerals may form porphyritic crystals.

SYENITE PORPHYRY is a fine-textured, highly porphyritic trachyte. It might equally well be placed in the granitoid group (syenites). The phenocrysts equal or exceed the groundmass in amount. The groundmass is frequently coarser than that of the average trachyte.

Trachydolerite is a name which has been variously used for rocks intermediate between trachytes and basalts, and trachytes and andesites, etc. The trachydolerite of Cripple Creek is a porphyritic rock composed of orthoclase, plagioclase, pyroxene, biotite and analcite. The principal minor minerals are titaniferous iron-ore and apatite. The phenocrysts are oligoclase, andesine and pyroxene. Orthoclase and albite occur in the groundmass.

Latites, Latite Porphyries and Monzonite Porphyries, rich in alkali feldspars (orthoclase and soda-orthoclase), or high in potash and soda, might be included here.

Vulsinite is a variety of latite having phenocrysts of orthoclase, sanidine and plagioclase. Augite and biotite are generally present.

Ciminite is a variety of latite containing phenocrysts of augite, olivine and feldspar. Sanidine and labradorite are the feldspars.

Banakite is a porphyritic rock composed largely of the alkali feldspars, labradorite, and subordinate amounts of augite and biotite. The phenocrysts are mainly labradorite.

LAMPROPHYRES are rocks occurring mainly in dikes, sheets and small intrusive bodies. They are composed of orthoclase, plagioclase, biotite, hornblende and augite, with iron-oxides and apatite. The dark minerals commonly exceed the light in amount, and thus give a dark color to the rock. The porphyritic varieties contain phenocrysts of the dark minerals: biotite, augite or hornblende. Biotite is the most abundant dark mineral of the common lamprophyres. Owing to peculiar conditions of crystallization, complete crystal boundaries are very common even in the non-porphyritic rocks and the groundmass of the porphyritic.

Minette (*Mica Trap*) is a mica lamprophyre in which orthoclase is the chief feldspar. Biotite is frequently the most important mineral both in the form of phenocrysts and as a constituent of the groundmass. Hornblende and augite when prominent form *Hornblende Minette* and *Augite Minette.* Olivine occurs, but not as a phenocryst. The color of minettes ranges from brown to grayish-brown, and almost black. They weather readily.

Kersantite is a mica lamprophyre similar to minette, but the chief feldspar is plagioclase. Biotite is very abundant in the groundmass, and hornblende is rarely an important constituent.

Vogesite is a lamprophyre in which orthoclase is the chief feldspar, but hornblende or augite, or both, have largely taken the place of biotite. When the chief dark mineral is augite, the rock may be called *Augite Lamprophyre,* and when hornblende is dominant, *Hornblende Lamprophyre.* The lamprophyres of the Trinidad area are mainly hornblende lamprophyres.

C. THE TRACHYTIC GLASS GROUP

The glassy rocks of this family include: TRACHYTE-OBSIDIAN, *Trachyte-Perlite, Trachyte-Pumice,* and *Hyalotrachyte*—a trachyte with glassy groundmass. They are very rare, and are practically indistinguishable, without chemical tests, from the corresponding rocks of the granite-rhyolite family.

D. THE TRACHYTIC TUFFS AND BRECCIAS (FRAGMENTAL) GROUP

The tuffs and breccias of this family are not easily distinguished from those of the preceding families. Sanidine is somewhat characteristic of trachytes, and would be an aid in identifying the breccias.

NEPHELITE SYENITE-PHONOLITE DIVISION

The textural groups are as follows:

A. The nephelite syenites, granitoid.

B. The phonolites and tinguaites, felsitoid.

C. The glasses, glassy.

D. Phonolite tuffs and breccias, fragmental.

In mineral composition the rocks of this division differ from those of the syenite-trachyte division in that they contain one or more of the feldspathoid minerals nephelite (elæolite), leucite, sodalite, and others. In chemical composition they are lower in silica and higher in aluminum, sodium and potassium. The average composition of 145 samples and the range of composition are shown by the following tables:

	Average Composition (per cent)	Range of Composition (per cent)
SiO_2	55.09	60.29 to 50.36
Al_2O_3	20.27	25.26 to 8.22
Fe_2O_3 FeO	4.78	11.60 to 1.86
MgO	0.82	1.10 to 0.10
CaO	2.88	9.05 to 0.25
Na_2O	7.96	11.62 to 1.90
K_2O	5.75	10.05 to 1.08

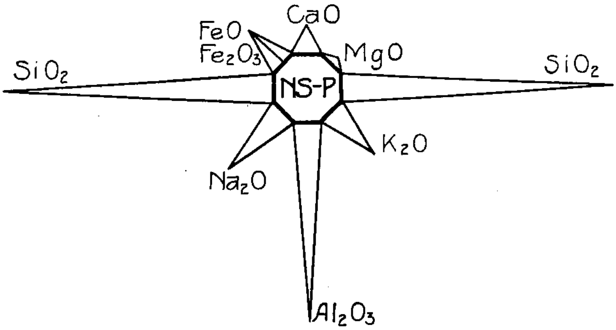
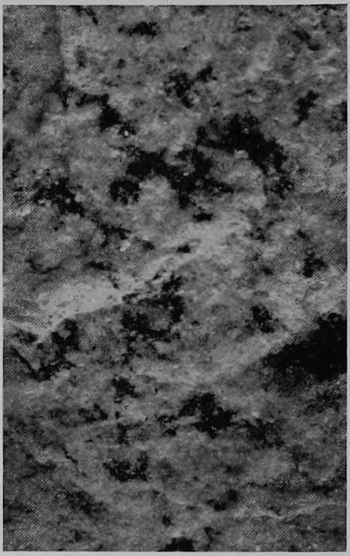


Fig. 52. Diagram to illustrate the average chemical composition of the rocks of the nephelite syenite-phonolite division of the family.

A. THE NEPHELITE SYENITE GROUP, GRANITOID

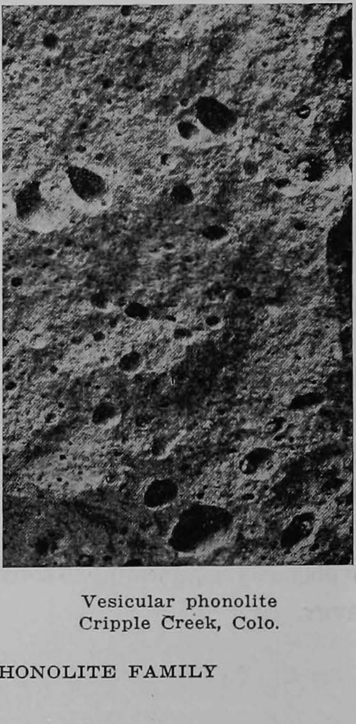
Nephelite syenites (elæolite syenites) show a wide range of texture, and very coarse, almost pegmatite, grain is not uncommon. Owing to the resemblance between nephelite and feldspar, it is difficult to distinguish fine-grained nephelite syenite from other syenites. In the coarse-grained forms the greasy or oily luster and less perfect cleavage of the nephelite are readily noticeable. Nephelite is quite commonly bluish or greenish-gray, while the associated feldspars rarely show these colors. Nephelite and leucite may occur as phenocrysts, forming Nephelite Porphyry and Leucite Porphyry.

Nephelite syenite
Cripple Creek, Colo.



Nephelite syenite
(Litchfieldite)
Litchfield, Me.

Phonolite
Cripple Creek, Colo.



Vesicular phonolite
Cripple Creek, Colo.

NEPHELITE SYENITE-PHONOLITE FAMILY

NEPHELITE SYENITE is a rock composed of alkali feldspars, nephelite, and one or more of the dark minerals: hornblende, biotite, pyroxene. One or more of the other feldspathoid minerals may be present. Zircon, apatite, titanite and magnetite are the common minor minerals, though zircon is sometimes present in such amount as to justify the name *Zircon Syenite.* Olivine is rare.

Varieties of nephelite syenite are based upon mineralogical differences. Few, if any, of these varietal names have come into general use.

LITCHFIELDITE (Litchfield, Maine) is one in which albite forms probably one-half the rock. Orthoclase, microcline, nephelite, sodalite, cancrinite and biotite (deep green) are present.

Foyaite is a name which has been variously used:

1. A nephelite syenite, with hornblende as the chief dark mineral.
2. Nephelite syenite, with ægirite and ægirite-augite, and in some cases hornblende or biotite.
3. General name for nephelite-syenite. The second use is probably most satisfactory.

DITROITE contains considerable blue sodalite.

Miascite is a biotite-nephelite syenite.

Laurdalite is rich in dark minerals, such as brown mica, green hornblende, and brown or purple augite.

SODALITE SYENITE is one in which sodalite is the prominent feldspathoid mineral.

LEUCITE SYENITE is one rich in leucite or pseudomorphs of orthoclase, nephelite, muscovite, and other minerals after leucite. It is sometimes called *Pseudoleucite Syenite.*

B. THE PHONOLITE, TINGUAITE GROUP, FELSITOID

The phonolites are usually very close-textured or dense rocks, varying in color from greenish-gray to brownish-gray and gray. In the non-porphyritic varieties it is seldom possible to recognize any of the component minerals, which, as a rule, include mainly orthoclase, sanidine, microcline, albite, nephelite. Leucite, sodalite, augite, occasionally plagioclase and hornblende, and rarely biotite and olivine, may be present. They are practically always completely crystalline. In the porphyritic varieties sanidine, microcline, nephelite, leucite, and occasionally augite may form phenocrysts. When nephelite is very abundant, a fresh surface of phonolite shows a dull-glassy luster or oily-glassy luster. Phonolites commonly break into slabs or plates, which give a ringing sound when tapped with the hammer. The principal occurrences of phonolite in Colorado are those of the Cripple Creek area.

PHONOLITE consists chiefly of sanidine or microcline, nephelite, and commonly one or more of the other feldspathoid minerals: sodalite, hauynite and noselite. Pyroxene, hornblende and biotite are sometimes present, but rarely in large amounts. Phonolite is a common rock in the gold-mining camps where telluride ores prevail. The easiest method of identification is to powder a small fragment and boil it in dilute nitric acid for a few minutes, then pour off the clear liquid and boil it down almost to dryness. If the rock is phonolite, a jelly-like mass will form in the test-tube.

LEUCITE PHONOLITE (leucitophyre) is one in which leucite is present in considerable amount. The name is also used for a rock in which leucite takes the place of nephelite.

LATITE PHONOLITE, rich in alkali feldspars or high in the alkalies potassium and sodium, might be included here.

Tinguaite consists mainly of alkali feldspar, nephelite, and considerable ægirite or ægirite-augite. Sodalite, leucite and biotite may be present.

Orendite is composed of leucite, sanidine, diopside, phlogopite (brown mica), and a little amphibole. The mica is almost phenocrystic. The rock is of a yellowish-gray color and vesicular.

Wyomingite is much like orendite, but has a glassy base.

C. THE GLASSY GROUP

Rocks with a glassy luster are very rare in this division of the syenite-trachyte family. PHONOLITE-OBSIDIAN occurs on the island of Teneriffe, PHONOLITE-PITCHSTONE is found near Weipert, in Austria, and LEUCITE PHONOLITE-PUMICE is reported from Olbruck.

D. PHONOLITE TUFFS AND BRECCIAS

Phonolite tuffs and breccias are not common. The noted "breccia" of the Cripple Creek mines consists of phonolite and latite-phonolite. While the term "breccia" is the most appropriate for the whole mass of rock, there are local bodies of tuff and agglomerate. In color the breccia ranges from blue-gray to reddish and purplish. The weathered rock is generally light yellow to brownish. In the greater part of the breccia the fragments range in size from an inch in diameter down to dust particles. Occasionally blocks three feet or more in diameter are found.

Many other rare rocks might be added to the list of those more or less closely related to the nephelite syenite-phonolite division. Among the granitoid are: *Theralite, Essexite, Teschenite, Urtite, Sussexite, Sodalite Rock, Tawite, Ijolite, Nephelinite, Missourite* and others. Among the felsitoid are: *Tephrite, Leucite Tephrite, Basanite, Leucite Basanite, Leucitite, Monchiquite* and *Alnoite.*

THE GABBRO-BASALT FAMILY

This family includes those basic rocks having, in general, the chemical and mineral composition of the gabbros. They may be divided, as in preceding families, into the following groups:

A. The gabbros, granitoid.
B. The diabases and basalts, felsitoid.
C. The glasses, glassy texture and luster.
D. The tuffs and breccias, fragmental.

The following table, from analyses of 200 specimens, shows the average chemical composition and the range of composition:

	Average Composition (per cent)	Range of Composition (per cent)
SiO_2	49.01	61.19 to 41.28
Al_2O_3	16.70	23.25 to 9.58
Fe_2O_3 FeO	10.72	20.86 to 3.35
MgO	6.25	17.42 to 1.00
CaO	9.32	15.74 to 2.47
Na_2O	3.08	5.99 to 0.97
K_2O	1.17	5.04 to 0.04

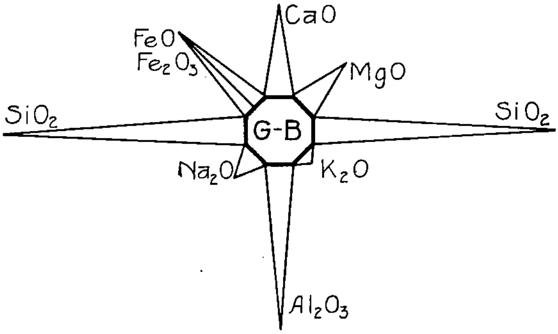


Fig. 53. Diagram to illustrate the average chemical composition of the rocks of the family.

The average analysis is characterized by an increase in the iron, calcium and magnesium, due to the increasing importance of the ferromagnesian minerals and the presence of the lime-rich members of the plagioclase series. The decrease in silicon, aluminum, sodium and potassium is due to the decreasing importance of the alkali feldspars and the soda-rich plagioclases. The very wide range of chemical composition is a noticeable peculiarity of the gabbro-basalt family. It results very naturally from the presence in the family of rocks so widely different in mineral composition as anorthosite, which may be almost pure plagioclase, and the pyroxene-rich gabbros which approach pyroxenite and may contain but little besides pyroxene. The very high upper limit of potassium is found in an orthoclase gabbro.

SPECIFIC GRAVITY: The rocks of this family, especially the dense basalts, are noticeably heavier than those of the preceding families. This is due to the abundance of the dark minerals.

COLOR: As the dark-colored minerals predominate, the prevailing color of the gabbro-basalt family is dark. In the gabbro group dark-gray to greenish-gray to greenish-black are the commonest colors, while gray, greenish-gray and grayish-black are the prevailing colors of diabases and basalts. The glasses are very dark-colored, and the tuffs and breccias are noticeably darker than those of the preceding families. Rusty-red or brown and dull, lusterless green are common colors in altered rocks in all textural groups of this family.

CRYSTALLIZATION: Glassy rocks are not common in this family, but they are known, and an uncrystallized remnant is not uncommon in certain types of basalt. The low temperature at which final solidification takes place (about 1000°-1100° C) affords a long period for crystallization, except on the immediate surface of lava flows and the contact surfaces in dikes and sheets. The porphyritic texture (fabric) is somewhat common, but less so than in the preceding families. Complete crystal boundaries are rather common in the groundmass of the basalts, and in the pyroxenes and olivines of all the textural groups.

TEXTURE: The textural range of the gabbro-basalt family is very wide, and has led to the use of the names "diabase" and "dolerite" for rocks intermediate in texture between the gabbros and the basalts. Many gabbros are very coarse-textured. On the other hand, many basalts are extremely dense or felsitic.

STRUCTURAL FEATURES: The vesicular structure is very common in basalts. The cavities or vesicles are bubble-shaped and smooth-walled, and were occupied by steam or other gases during the earlier part of the solidification of the rock. The vesicles are commonly much more numerous and symmetrical in the upper part of a basaltic flow than in the lower part. When these vesicles become filled with secondary minerals as a result of alteration of the basalt, the rock is said to be amygdaloidal. The amygdules include calcite, quartz, zeolites, and other minerals.

Spheroidal sundering is particularly common in basalts, diabases and dolerites. Columnar jointing is more common in basalts than in any other rock type.

MINERAL COMPOSITION: Augite, olivine and plagioclase are the most important minerals of the family. Hypersthene and bronzite occur in certain varieties of gabbros and basalts, but are not generally important. Hornblende is rather rare, except in altered gabbros, where it has resulted from the alteration of augite. Alkali feldspars, quartz and biotite are rare. Nephelite and leucite occur in a few basalts. Magnetite and apatite are the commonest minor minerals. The plagioclases are chiefly labradorite, bytownite and anorthite. Augite and olivine are the commonest porphyritic crystals, but feldspars and even quartz occur.

TRANSITIONS AND RELATIONSHIPS: As pyroxene increases, the pyroxenites are approached, and olivine-rich gabbros are closely related to the peridotites. The basalts show transitions to the augite andesites.

OCCURRENCE: Gabbros are not widely distributed in America, but basalt is extremely abundant. Gabbros are abundant in the White and Adirondack Mountains, near Baltimore, around Lake Superior, and are known in a number of the western states. In Colorado gabbros occur in the Telluride, Engineer Mountain, and other parts of San Juan. Basalts are very extensively developed in Idaho, Washington, Oregon, the Lake Superior region, and New England. Colorado has many large areas covered with basaltic rocks in the form of sheets or flows. Some of the most noted are the Table Mountains, near Golden; Fisher's Peak, near Trinidad; Mesa de Maya, in Las Animas County; the Elk Head Mountains; large areas both east and west of the southern end of San Luis Park; areas on the divide, between North and Middle Parks; in the northeastern part of Eagle County; on the White River Plateau, and on Grand Mesa.

Gabbros occur mainly as intrusive bodies of large size, but also as dikes. Basalts occur as dikes, but much more commonly as sheets or flows.

Field and General Classification of the Rocks of the Gabbro-Basalt Family

GRANITOID GROUP

Gabbro: *Olivine Gabbro, Hornblende Gabbro, Gabbro-Diorite, Quartz Gabbro, Mica Gabbro* or *Biotite Gabbro, Orthoclase Gabbro, Hypersthene Gabbro* or *Hyperite, Norite, Dolerite.*

Syenite: *Anorthosite* is a rock composed largely or wholly of plagioclase, commonly labradorite. Other *Gabbros* rich in feldspar may be classed as *Syenite.*

Diorite: *Gabbro-Diorite* is often very rich in hornblende. This and *Hornblende-Gabbro* may sometimes be classed as *Diorite.*

FELSITOID GROUP

Basalt: *Diabase* of the different varieties, *Dolerite* of fine texture, *Quartz Basalt, Hornblende Basalt, Hypersthene Basalt, Mica Basalt, Olivine Basalt, Orthoclase Basalt* or *Absarokite, Leucite Basalt, Nephelite Basalt.*

Basalt Porphyry: *Gabbro Porphyry, Dolerite Porphyry, Diabase Porphyry, Basalt Porphyry, Melaphyre.* Practically all the *Dolerites, Diabases* and *Basalts* may be porphyritic. The mineral occurring as phenocrysts will give the specific name to the rock, as *Quartz Basalt Porphyry.*

THE GLASSY GROUP

Obsidian: *Tachylite (Hyalomelan)* or *Hyalobasalt,* and *Variolite.*

FRAGMENTAL GROUP

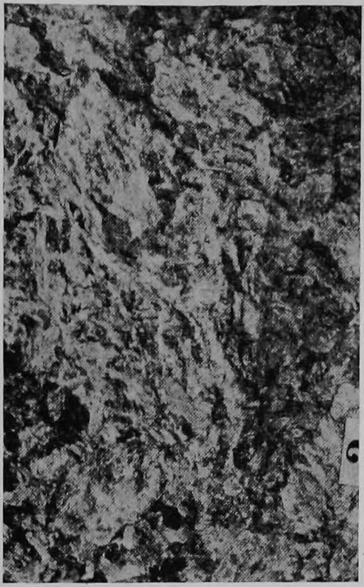
Basalt Tuff: *Basalt Tuff.*

Basalt Breccia: *Basalt Breccia, Dolerite Breccia.*

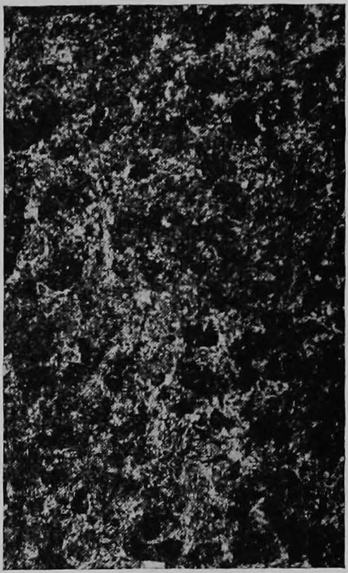
A. THE GABBRO, NORITE, ANORTHOSITE GROUP, GRANITOID

Gabbro is a general name for granitoid rocks composed essentially of pyroxene and plagioclase. The presence or prominence of other minerals gives varieties of gabbros. Coarse textures are common, but pegmatitic forms are rare.

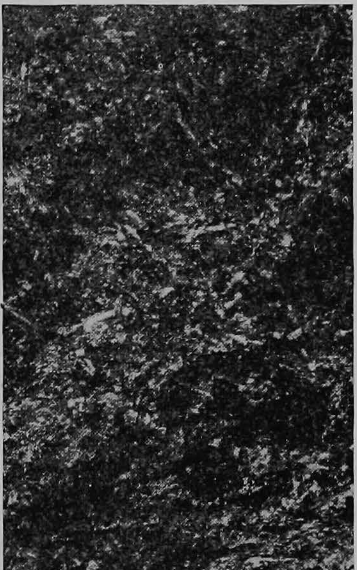
Olivine Gabbro is one in which olivine is reasonably abundant.



Gabbro
West Duluth, Minn.



Hornblende gabbro
Sunenburg, Vt.



Anorthosite

Anorthosite
Duluth, Minn.

GABBRO-BASALT FAMILY

HORNBLENDE GABBRO is one containing hornblende. If the hornblende is a primary mineral, the rock may be regarded as intermediate between gabbro and diorite.

GABBRO-DIORITE is a name applied to gabbro in which hornblende is developed from the alteration of pyroxene.

Quartz Gabbro is one in which a small amount of quartz occurs.

Mica Gabbro, Biotite Gabbro, is one in which biotite is noticeably present.

Orthoclase Gabbro contains orthoclase in addition to the usual plagioclase. It occurs in the Lake Superior region, in the Adirondacks, and elsewhere.

HYPERSTHENE GABBRO contains hypersthene, but not as the chief pyroxene. Hyperite is another name for this rock.

NORITE is a gabbro having hypersthene, bronzite or enstatite as the chief or only pyroxene. Varieties of norite are: *Olivine Norite, Quartz Norite, Hornblende Norite, Mica Norite,* etc.

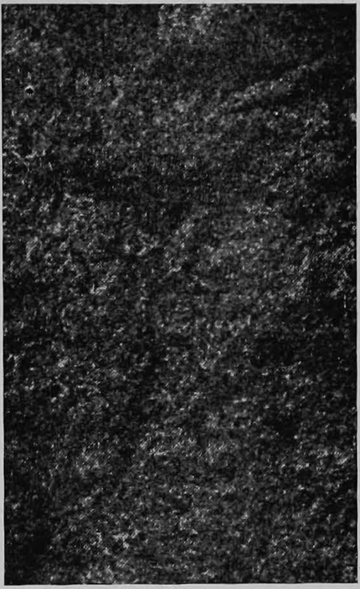
ANORTHOSITE is a gabbro consisting almost entirely of basic plagioclase, most commonly labradorite, but ranging from labradorite to anorthite. Pyroxene, hornblende, olivine, biotite and magnetite—one or more—may be present in small amount. The feldspar grains are usually large, and a roughly parallel arrangement is sometimes noticeable. Anorthosites are abundant in the Adirondacks, the Lake Superior region, Quebec, and in the Laramie Range, Wyoming. By the increase of augite they grade into the normal gabbros.

DOLERITE may be regarded as a coarse-textured basalt or a fine-textured gabbro, from which it differs in no important particular in either chemical or mineral composition. (It might be placed in the next group.)

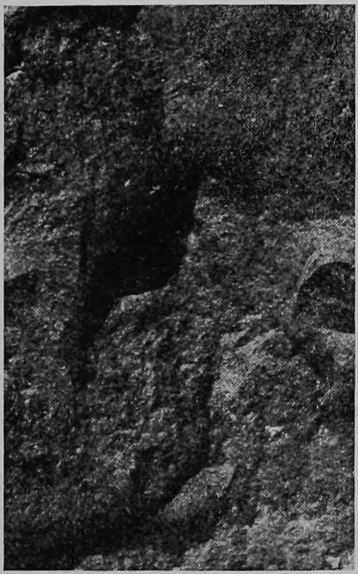
B. THE DIABASE AND BASALT GROUP, FELSITOID

Diabase and *Dolerite* form a textural transition from the gabbros to the basalts. In mineral composition the *Basalts* have not quite so wide a range as the gabbros. They are composed mainly of a finely crystalline mass of pyroxene, plagioclase, and more or less olivine, hornblende, biotite and magnetite. Leucite and nephelite occur in certain varieties, and quartz and orthoclase are sometimes present. Glass occurs in small amount in some basalts. The porphyritic fabric is rather common, and while augite and olivine are the commonest phenocrysts, any of the other minerals may form porphyritic crystals. The fact that the dark minerals are commonly greatly in excess of the light gives the rock

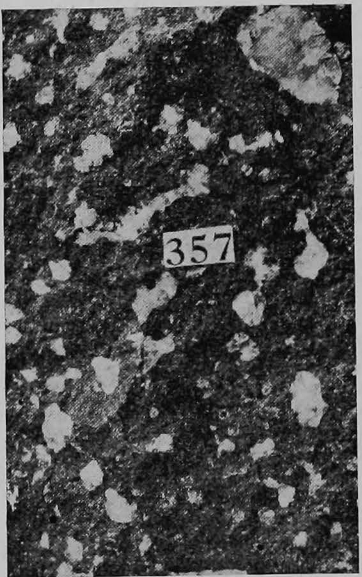
Diabase



Dolerite
Valmont, Colo.



Basalt



Amygdaloidal basalt

GABBRO-BASALT FAMILY

a uniformity of color which makes it very difficult to distinguish the component minerals of non-porphyritic basalts, even with a good lens. The porphyritic varieties are commonly named according to the phenocrysts. The non-porphyritic varieties, if distinguished at all, must be classified by aid of the microscope.

DIABASE is a rock intermediate in texture between the gabbros and the basalts, and composed of the usual minerals of the gabbro group, but having certain textural peculiarities. The "diabase" texture shows long, almost rectangular crystals of feldspar, separated by irregular grains of pyroxene. The feldspar crystallized first, and took on almost complete crystal boundaries. The "ophitic" texture differs from the diabase texture in that the feldspar crystals are bedded in the pyroxene crystals. The diabase texture may sometimes be seen by the unaided eye, but the ophitic is rarely visible without a very strong lens. Weathered diabase is often called greenstone.

Varieties of diabase depend upon the peculiarities of mineral composition, and include: *Olivine Diabase, Quartz Diabase, Hypersthene Diabase,* and others. The names explain themselves.

BASALT is a general name for the felsitoid or felsitic rocks of the family. The varieties are based upon differences of mineral composition, as in the gabbros and diabases.

QUARTZ BASALT is one in which quartz occurs either as phenocrysts or in the groundmass.

Hornblende Basalt contains hornblende (commonly dark brown), in addition to the usual minerals.

Hypersthene Basalt contains hypersthene, and as a rule augite and olivine.

Mica Basalt adds biotite to the commoner gabbro-basalt minerals.

OLIVINE BASALT is one in which olivine is present in fair amount, either as phenocrysts or in the groundmass.

Orthoclase Basalt (absarokite) is a basalt having phenocrysts of augite and olivine in a groundmass containing orthoclase, and sometimes biotite, in addition to the usual minerals.

LEUCITE BASALT is one in which leucite or pseudomorphs after leucite are present.

NEPHELITE BASALT contains nephelite.

MELAPHYRE is a term used in a variety of ways:

1. An altered porphyritic basalt in which secondary minerals, such as chlorite, serpentine, epidote, and others, may be developed;

2. Porphyritic rock of dark color, containing phenocrysts of feldspar;

3. A porphyritic olivine diabase.

BASALT PORPHYRY is a basalt in which phenocrysts compose a fairly large part of the rock.

GABBRO PORPHYRY is a rock in which the phenocrysts form such a large proportion of the rock that it has the general appearance of a granitoid variety.

C. THE GLASSES, GLASSY TEXTURE AND LUSTER

Glassy rocks of the gabbro-basalt composition are very rare. They occur mainly as surfacings and borders of basalt flows, or at the contact of basalt dikes with the containing rock. These glasses cannot be distinguished from those of preceding families, except by their field relationships, or chemical analysis, or occasionally by the presence of phenocrysts of olivine and augite.

Tachylite (Hyalomelan) is a basaltic glass, and might be called basaltic-obsidian. *Hyalobasalt* is another name for the same rock.

Variolite is a spherulitic basaltic glass.

D. THE TUFF AND BRECCIA GROUP, FRAGMENTAL

Basaltic tuffs and breccias are of darker color than those of the preceding families. The presence of olivine and augite crystals in the fragments will help to determine the breccias. The Hayden Survey reports a *Doleritic Breccia* in Middle Park, but it appears to be andesitic.

PERIDOTITE, PYROXENITE-LIMBURGITE, AUGITITE AND RELATED ROCKS

These rocks may be regarded as forming a family, although the relationships are not so close as in the other families. They are very basic, consist almost entirely of ferromagnesian minerals, and are consequently of dark color and high specific gravity. In many instances they may be regarded as extreme types of the gabbro-basalt family. Transitions from olivine gabbro and olivine norite to peridotite by the increase of olivine, and from normal gabbro to pyroxenite by increase of augite are not uncommon in the field relations of these rocks.

The rocks of this family may be included in two groups:

A. Peridotites, pyroxenites, dunite, granitoid.

B. Augitite, limburgites, monchiquite, felsitoid.

Table I gives the average of the analyses of eleven pyroxenites, and Table II the average composition of thirty-eight peridotites. The diversity of the rock types in this family makes any statement of the range of chemical composition valueless.

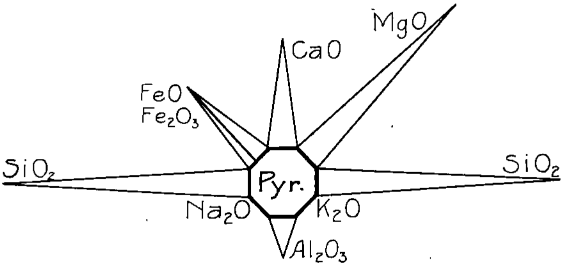


Fig. 54. Diagram to illustrate the average chemical composition of pyroxenites.

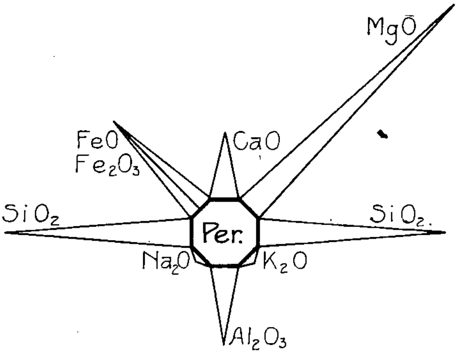


Fig. 55. Diagram to illustrate the average chemical composition of peridotites.

	Table I (per cent)	Table II (per cent)
SiO_2	50.45	38.00
Al_2O_3	4.15	8.00
FeO Fe_2O_3	10.30	12.50
MgO	21.66	29.50
CaO	11.00	6.70
Na_2O	0.30	0.075
K_2O	0.08	0.087

The low silica, alumina, soda and potash are characteristic. The high contents of iron, magnesium and calcium oxides are in keeping with the mineral composition.

COLOR: The commonest colors are dark greenish-brown, greenish-gray, grayish-black and black. The presence of much enstatite, bronzite or hypersthene gives a bronzy tone, while the dunites may be light olive-green in color. Weathering gives most of these rocks a dull greenish color. They are, as a rule, extremely tough and hard to break.

CRYSTALLIZATION: Complete crystallization is the rule, though augitite and limburgite are believed by many to contain glass in the groundmass. Monchiquite is doubtful in this respect.

TEXTURE: The range of texture is similar to that of the gabbro-basalt family. The porphyritic fabric is common in the felsitoid group, and occurs rarely in the granitoid rocks.

STRUCTURAL FEATURES: There are no marked peculiarities of structure. Spheroidal sundering is not uncommon.

MINERAL COMPOSITION: Pyroxenes, olivine, hornblendes and biotite are the chief minerals, but plagioclase, magnetite, ilmenite, garnet, apatite, chromite, and other minor minerals are common. The pyroxenes include mainly augite, hypersthene, bronzite and diallage, but others occur. Different varieties of olivine are found, but the common green variety is the most important. Common hornblende and the soda-bearing varieties occur.

TRANSITIONS AND RELATIONSHIPS: These have been suggested above, and in the chapter on the gabbro-basalt family.

ALTERATION: By far the commonest alteration mineral is serpentine, but hornblende is in many instances an intermediate product.

OCCURRENCE: They are commonly associated with the gabbro-basalt family, but independent occurrences are not uncommon. Peridotites occur with the Cortland series on the Hudson, with the gabbros near Baltimore, in northern Michigan, and elsewhere. In Colorado a peridotite containing hornblende and hypersthene occurs in the Rosita Hills.

Pyroxenite occurs near Baltimore, in Maryland, in North Carolina and in California, but it is nowhere important in this country. In Colorado a pyroxenite dike occurs in the Tungsten area of Boulder County.

Dunite is abundant in North Carolina. Augitites and limburgites occur in dikes. Limburgite is found in the Tungsten area of Boulder County, Colorado.

Field and General Classification of the Rocks of the Peridotites, Pyroxenites, Limburgites and Related Rocks

GRANITOID GROUP

Peridotite: *Peridotite, Mica Peridotite, Picrite, Hornblende Peridotite, Hornblende Picrite, Dunite. Kimberlite* is commonly porphyritic.

Pyroxenite: *Pyroxenite, Websterite.*

Gabbro: With a decrease of pyroxene and the appearance of plagioclase there is a transition from the *Pyroxenites* to the *Gabbro.*

Hornblendite: *Hornblendite, Cortlandite.*

Diorite: As the hornblende decreases and feldspar increases there is a transition to *Diorite.*

Serpentine Rock: *Gabbros, Peridotites, Pyroxenites* and *Hornblendites* may become completely serpentinzied.

FELSITOID GROUP

Basalt and Basalt Porphyry: *Limburgite, Augitite, Monchiquite, Melelite Basalt.*

A. PERIDOTITE, PYROXENITE, DUNITE GROUP, GRANITOID

Peridotite consists mainly of olivine, but small amounts of other minerals—such as pyroxene, hornblende, mica and minor minerals—are usually present. Many varieties are recognized by the aid of the microscope. They are based upon the minerals accompanying the olivine. *Mica Peridotite* contains considerable biotite with spinel and occasionally a little plagioclase.

Picrite is a peridotite containing augite and occasionally biotite, hornblende, plagioclase. It is sometimes porphyritic (picrite porphyry).

Hornblende Peridotite, Hornblende Picrite, contain considerable hornblende.

Kimberlite is a peridotite containing a fair amount of biotite and some pyroxene. It is commonly porphyritic. It is the matrix of the diamond in the South African mines.

Dunite is very largely olivine, but small amounts of other peridotite minerals occur.

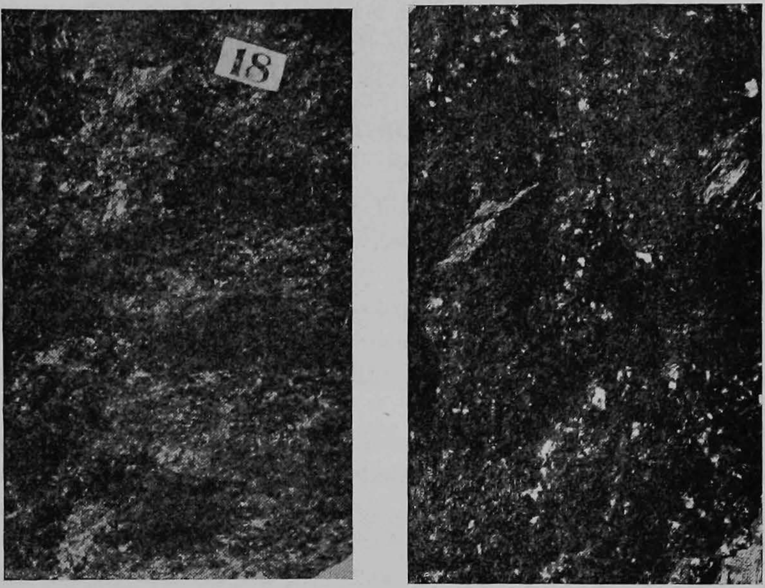
Pyroxenite is a rock composed mainly of pyroxene. But olivine, hornblende, feldspar and minor minerals may be present. Varieties are based upon the kind of pyroxene and the accompanying minerals.

Websterite is composed of augite and one or more of the orthorhombic pyroxenes: hypersthene, bronzite, enstatite.

Hornblendite is a rock composed mainly of hornblende, but pyroxene, olivine and biotite may be present.

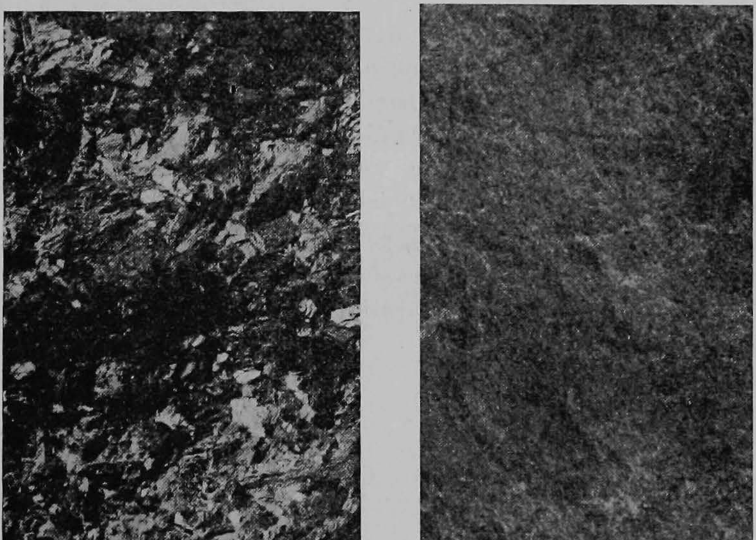
Cortlandite is chiefly hornblende, but augite and hypersthene, and occasionally plagioclase, may occur.

Serpentine (rock) is a secondary rock derived mainly from primary rocks rich in olivine. But pyroxenites, gabbros and the



Pyroxenite
Pikesville, Md.

Peridotite
Baltimore Co., Md.



Hornblendite
Hahns Peak, Colo.

Serpentine

PYROXENITE-PERIDOTITE FAMILY

corresponding fine-grained types may yield secondary rocks so rich in serpentine as to be classed here. The rock commonly contains much mineral matter not changed to serpentine.

B. THE AUGITITE, LIMBURGITE, MONCHIQUITE GROUP, FELSITOID

Limburgite consists chiefly of olivine and augite, in a more or less glassy groundmass. Magnetite, ilmenite, feldspar, nephelite and hauynite may occur.

Augitite is a porphyritic rock having a groundmass (believed to be glassy) in which augite, magnetite and other minor minerals are bedded. Some petrologists think that what appears to be glass may be analcite.

Monchiquite is composed mainly of augite and a soda hornblende, in a groundmass of analcite or a glass having the composition of analcite. Biotite and olivine are often present. Hornblende, augite and biotite may form phenocrysts.

Melilite Basalt consists of augite, olivine and melilite, with more or less magnetite, chromite and nephelite.

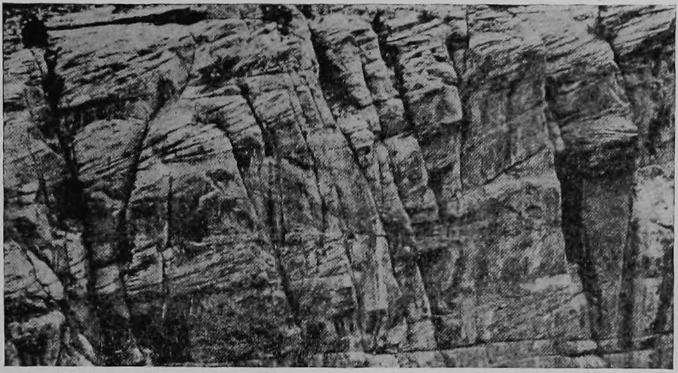
SEDIMENTARY ROCKS

Under this general name are included all rocks derived from pre-existing rocks or other materials, whether organic or inorganic. The agencies by which they have been brought to their present form and position include: wind, running water, life, chemical change, chemical precipitation, weathering processes, and others. Sedimentary rocks may be grouped as follows:

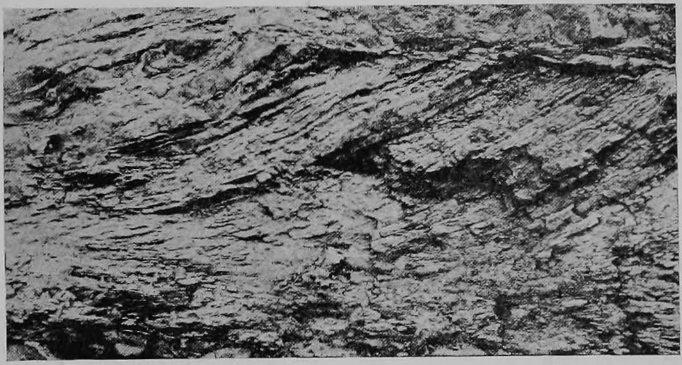
I. Sand and Gravel Rocks—Arenaceous.
II. Clay Rocks—Argillaceous.
III. Rocks Chiefly of Organic Origin:
  1. Calcareous.
  2. Carbonaceous.
  3. Siliceous.
  4. Phosphatic.
IV. Chemical Precipitates, Chiefly.

I. SAND AND GRAVEL ROCKS—ARENACEOUS

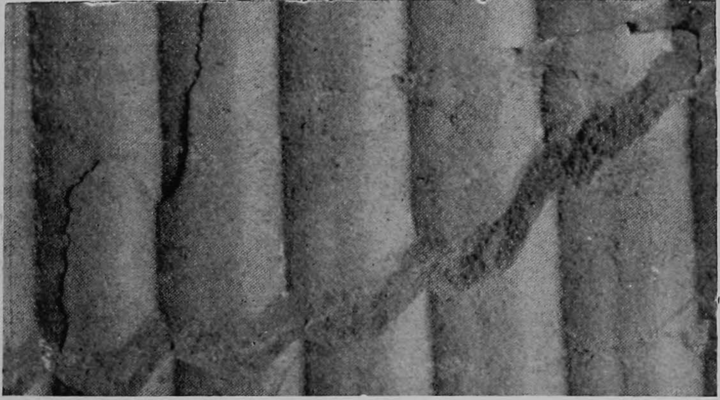
The materials of these rocks are derived from other rocks and consist mainly of sand, gravel, rock fragments, boulders, and more or less cementing material. Quartz grains are by far the most



Cross-bedding in sandstone

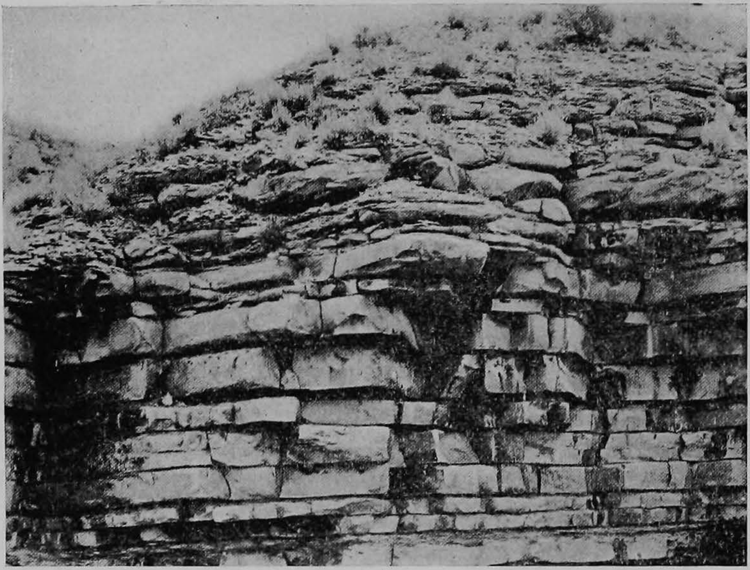


Cross-bedding in shale

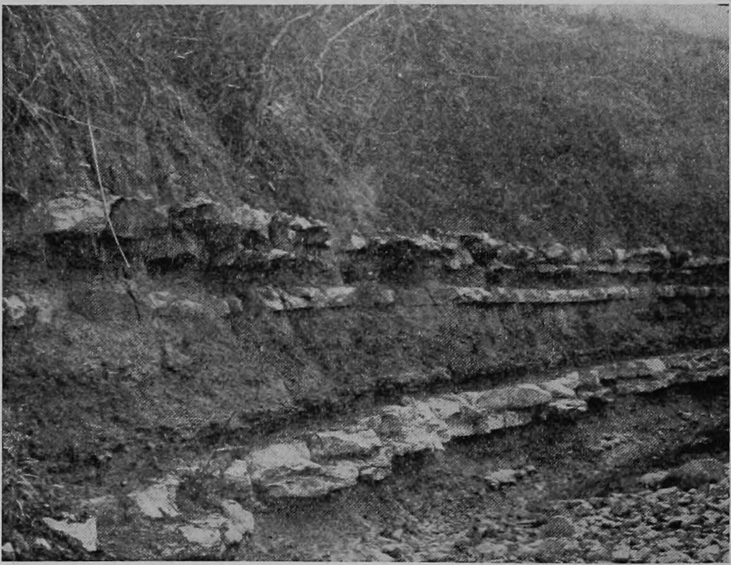


Ripple-marks in standstone

SEDIMENTARY ROCK STRUCTURES



Jointing and stratification of limestone strata



Alternation of hard and soft strata (limestone and shale)

SEDIMENTARY ROCK STRUCTURES

important constituent of sand, but every mineral contained in the rocks of the outer part of the earth may be found in sands and sandstones. Quartz, feldspar, mica, iron ores, zircon, rutile, garnet, tourmaline, hornblende and pyroxene are the commonest. But grains of gem minerals, gold, silver, copper, platinum and many others are found in sand and sandstone. Since quartz grains compose by far the largest part of sands and sandstones, it is evident that the rocks containing quartz grains have been by far the most important original source of their materials. Gravel and boulders consist mainly of igneous rocks, but pebbles of quartz and pebbles and boulders of sedimentary rocks are common. The physical condition of the materials will depend upon their history after they are separated from the parent rock. If their journey to the sea, or their stay on the beach, has been long, they will be rounded and smoothed by wear. But if these have been short, they may be sharply angular or subangular when they enter into the make-up of the sedimentary rocks.

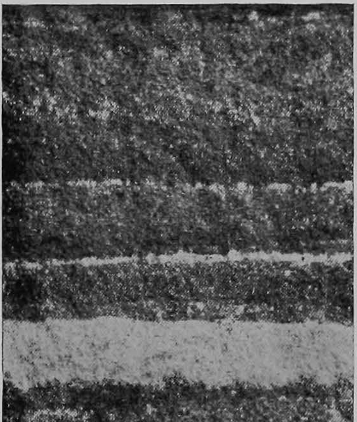
The chief cementing materials are silica, calcite, iron oxides, magnesium and iron carbonates, and clay. With the exception of clay, these cementing materials are deposited from solutions circulating through the rock material. The clay is deposited with the materials between which it forms the bond.

SAND is mineral matter in grains resulting from the disintegration of rocks. When first formed, the grains are sharp and angular, but when driven by the wind or water they become subangular or round. *Siliceous* sand is by far the commonest, but *calcareous* sands are abundant along sea-coasts where limestone, or shells, or coral rocks are being broken down. *Ferruginous sands* (black sands) are common where the assorting work of water or wind has removed the lighter siliceous sand and left the heavier iron ore grains behind.

Greensand, or glauconitic sand, contains more or less glauconite (green silicate of potash and iron) in small grains, often filling cavities in minute shells.

Uses: Sand as a commercial article is classified according to uses as: building sand—for mortars, cements and plasters; molding-sand—for iron and other metal casting; fire sand—a pure silica sand used for fire purposes about blast furnaces and various other metallurgical furnaces, and for ladle and cupola linings; engine sand—is a hard sand graded to definite size for sanding the rails of railways; filtration sand is used for large filter systems; glass

Conglomerate
Boulder, Colo.



Banded sandstone
Minnesota

Sandstone
Boulder, Colo.

sand is a very pure silica sand used in glass making. Large amounts of sand are used for ballast, road building, filling and reclaiming water fronts. It is used as a fire-proofing material, safe-filling, sound-proofing, wood filler, in paper making, etc., etc.

GREENSAND: The greensands of New Jersey and elsewhere are extensively used as a fertilizer especially in the gardening district about New York City.

GRAVEL is water-worn rock detritus, ranging in diameter from one-eighth of an inch to two inches.

Uses: The principal uses of gravel are as ballast, road material, concrete filler, grout, filtering material.

BOULDERS are more or less rounded blocks of rock, ranging in size from coarsest gravel to masses several feet in diameter. Boulders are formed from angular blocks by the work of running water, waves, and by decay.

SANDSTONE is sand formed into a solid rock by the cementation of the grains. The cement may be siliceous, calcareous, ferruginous or argillaceous. The color of sandstones having siliceous or calcareous cement is generally that of the sand grains, while those having ferruginous cement are commonly yellow, brown or red. Argillaceous cement usually gives a gray or blue-gray color, and may be detected by clay odor when the rock is moist.

VARIETIES OF SANDSTONE: *Quartz Sandstone, Siliceous Sandstone,* is one in which quartz grains form practically the entire rock. *Micaceous Sandstone* is one in which mica is present in noticeable amount. The rock may show a tendency to split into slabs along planes in which mica is abundant. *Ferruginous Sandstone* is one rich in iron either as a cementing material or in grains, or both. *Flagstone* is a sandstone which splits readily into flags or slabs of uniform thickness. *Glauconitic Sandstone* contains grains of glauconite in sufficient quantity to give it a greenish color. *Arkose, Feldspathic Sandstone, Granitic Sandstone,* is one composed of quartz, feldspar and mica derived from the disintegration of granite. The grains are usually angular, showing but little water-wear. *Argillaceous Sandstone* is one in which clay is present in considerable amount. *Graywacke* is composed of quartz, feldspar and other mineral grains, together with rounded or angular rock fragments of various kinds, in a cement which is more commonly siliceous, but may be calcareous or argillaceous or slaty. The commonest color is gray, but brown, black and green graywackes occur.

Uses: Sandstones are extensively used as building stones, and in road construction. Those varieties which break readily into slabs are used for paving or flagging. Pure silica sandstone is crushed for glass sand, and other purposes where pure silica is required. (See also the section on Building Stones.)

BRECCIA is similar to conglomerate, but the fragments are angular, and must have been formed into a solid rock near their place of origin.

Grindstone is a homogeneous, porous sandstone whose grains are cemented firmly enough to hold them up for cutting purposes, but not so firmly as to prevent a slow crumbling under use and cause the stone to "gum" and wear smooth.

Pulpstones are very large grindstones used in grinding wood-pulp for paper manufacture.

Colorado has first-class sandstones for these purposes in Gunnison, Boulder and other counties.

Whetstones are sharpening-stones cut from various rocks, such as sandstone, quartz-mica schist, novaculite, and others. The texture and cementation are similar to those desirable in grindstones. In some schist whetstones garnet forms the important cutting grains.

Oilstone is usually a finer-textured stone, with a fine but keen "bite," and a rather smooth wearing surface kept clean and sharp by means of oil. Novaculite and sand rocks of extremely fine porous texture and rather firm cementation are most satisfactory.

CONGLOMERATE, PUDDINGSTONE, is a rock composed of gravel, pebbles or boulders cemented together by finer material, such as consolidated sand, clay, quartz, calcite or limestone. The pebbles or boulders may be igneous or sedimentary, or both. The coarse materials were carried to the sea by strong river currents, and then spread by waves over the shallower parts of the sea-floor, where the cementing material was deposited among them. Widespread conglomerate is regarded as evidence of a migrating shoreline due to the advance of the sea upon the land.

II. CLAY ROCKS, ARGILLACEOUS ROCKS

Clay rocks are composed of the finest sedimentary material resulting from land waste. The characteristic minerals are those of the kaolin group, but the percentage of true kaolin minerals in the different members of the clay family varies from less than five to nearly one hundred. For convenience, these minerals will be called *Kaolin*. The materials commonly associated with it include fine *quartz sand, grains of feldspar, mica, hornblende, pyroxene* and *other minerals, minute grains of rock,* and materials deposited *from solution,* such as silica, iron oxides, calcium carbonate (calcite), calcium sulphate (gypsum), iron sulphide (pyrite), and others. By the increase of sand, and the corresponding decrease in clay substance, the rocks grade into argillaceous sandstones and common sandstones. As calcium carbonate increases, there is a transition to clayey limestones and limestones. With the increase of iron oxides, ochres and impure iron ores are formed.

Clay rocks give out a peculiar, characteristic odor when breathed upon.

When clay rocks are subjected to pressure, heat and moisture crystallization begins, and mica, hornblende, pyrite, fibrolite, garnet and other secondary minerals are formed. This crystallization may be regarded as the beginning of metamorphism, and all possible gradations are found between the sedimentary and the meta-sedimentary groups.

The chief source of kaolin is the alteration of feldspars, but it is derived from practically all rock-making minerals containing alumina and silica. In rock decay the alumina and the silica may come from different sources.

CLAY is a general name for fine mechanical sediment, sometimes rich in hydrous aluminous silicates, such as kaolinite, halloysite, and other members of the kaolin group. Fine mineral and rock grains, more or less decomposed, frequently form a large percentage of common clays. These, and materials deposited from solution, furnish most of the so-called impurities, such as iron, lime, magnesia, potash and soda. The color varies from white to gray and bluish-gray, buff, brown, red and black.

Mud is clay softened with water into a semi-solid mass.

Loam is a sandy clay containing more or less organic matter derived mainly from plants. In color it varies from gray to yellow, buff, brown, chocolate and black. The cultivated soils are loams varying in mineral composition and in the content of organic matter.

SOILS are the finely divided products of rock disintegration to which have been added the remains of plants and animals. Some soils have been formed in the places they now occupy while others have been carried to their present places by wind, water or the direct action of gravity. Soils in place commonly bear evidence as to the character of the rocks from which they were formed, and a gradation from perfect soil to almost fresh rock may sometimes be seen in wells, railway cuts and stream banks. Transported soils may contain materials from widely separated areas and from great distances.

By far the most abundant materials of soils are very fine rock fragments. Clayey soils contain, in addition, a small percentage of one or more of the kaolin minerals. The food required by plants consists mainly of potash, phosphoric acid, soda, magnesia, lime, sulphuric acid, silica, and sulphur. (Nitrogen is necessary to plant life, but it is not a natural part of the soil.) In order that plants may take up these foods they must be in soluble form. It is estimated that the average fertile soil to a depth of one foot contains, for each acre, about 87 tons of these food materials in soluble form. But the average weight of an acre-foot of soil is about 2,000 tons. The available plant food is, therefore, less than 5 per cent of the weight of the soil.

ADOBE is a silty, calcareous clay derived mainly from the decay of nearby rocks, and transported to its present position in part by sheet-wash and in part by wind. It is common in the valleys and on the lower slopes of mountains in the southwestern states. It is plastic and is used for sun-dried bricks.

LOESS is a fine, sandy clay of light color. It is commonly calcareous, and sometimes contains many calcareous concretions. It is probably, in large part, a wind deposit, derived from finely divided water sediments and from residual clays and other detritus on weathering surfaces. It is found in practically all the Mississippi Valley states, but is especially abundant near the main drainage courses. It is abundant in eastern Colorado.

TILL, GLACIAL CLAY, DRIFT, BOULDER CLAY, is a glacial deposit consisting of stiff, coarse, sandy, pebbly or stony clay, derived from the rocks over which the ice passed. It varies in composition according to the source from which it came. It is a mixture of all the products of glacial erosion, from the finest rock-flour to boulders. The color varies with the composition and the degree of weathering. It covers a very large area in the northern part of the Mississippi Valley and in the northeastern states. In Colorado it is found in the moraines of the local glaciers and in areas once occupied by glaciers in all the higher ranges.

Pipe Clay is a fine-grained, white, plastic clay, practically free from iron, but commonly high in silica.

FIRE CLAY: The term is properly applied to those clays which will withstand high temperatures without fusing or fluxing. The composition varies widely, but they are commonly high in kaolin, and must be low in the fluxing impurities, such as lime, ferric oxide, magnesia, soda and potash. Silica in certain proportions reduces the refractoriness, although silica alone is almost as refractory as kaolin. Fire clays vary widely in plasticity, texture and other physical properties. They are of both residual and sedimentary origin. Sedimentary fire clay frequently occurs under coal seams. In Colorado the best fire clay comes from the Dakota, but an inferior grade is associated with the coal of the Laramie and other formations.

BRICK CLAY is any clay which may be readily molded, and burned into bricks at comparatively low temperature. Brick clays vary widely in composition, plasticity, and in behavior when burned.

KAOLIN, CHINA CLAY, is a hydrous silicate of aluminum, derived mainly from the alteration of feldspars. In color it varies from pure white to buff, yellow, pink, rusty-brown and almost black. It is highly plastic, and when examined under the microscope is found to contain crystalline kaolinite in the form of thin hexagonal plates.

It is formed from the decay of rocks rich in feldspar, and is very likely to contain impurities derived from other minerals. Quartz is commonly present.

Halloysite is very similar to kaolinite, and is used for the same purposes. It varies in the degree of plasticity. *Indianaite* is probably a variety of halloysite. It is found in Lawrence County, Indiana, and to a limited extent elsewhere.

SHALE is a compact clay rock having a more or less perfect lamination, due to deposition, but sometimes emphasized by pressure. As a rule, shales split readily into thin plates. Kaolin is commonly the most important constituent, but quartz sand, white mica (mainly secondary), and other mineral and rock grains are generally present. As sand increases, shales grade into indurated silts and sandstones. They vary in color from gray to buff, yellow, brown and black. Varieties of shale depend upon differences of composition or physical characters. Some of the common kinds are:

Calcareous Shale is rich in calcium carbonate, as shown by effervescence when it is tested with acids.

Sandy Shale contains much sand, and grades into sandstone.

Ferruginous Shale is rich in iron oxides, which give the rock a yellowish-brown, brown or red color.

Carbonaceous Shale is one rich in carbon derived from plant (or animal) remains.

Bituminous Shale, Oil Shale, gives out a strong odor of bitumen when crushed or struck with a hammer; some shales are so rich in oil as to make their distillation profitable, and others will burn feebly.

Alum Shale is one in which soluble sulphates have developed as a result of the alteration of iron pyrite. They are a source of alum.

Laterite is a red or brown, iron-rich, sandy clay of cellular structure, formed by the disintegration of granite, gneiss and other rocks, in tropical regions where oxidation is rapid and complete. It is generally rich in ferric oxide and the hydrous oxides of aluminum; hydrargillite, gibbsite and others. On exposure to air it becomes hard and strong, and is used for sun-dried bricks. The name is sometimes made to include all highly ferruginous clayey products of weathering.

ECONOMIC: Almost every type of clay rocks finds a use in the industries. (See the section on Clays.)

Kaolin (*China Clay*) is extensively used in the manufacture of porcelain.

Fire Clay is used for furnace and flue linings, crucibles, and other purposes where resistance to high temperature is required.

Fullers' Earth is used for scouring and cleaning cloth, and more extensively for clarifying fats, oils and greases. The coarser types of clay are used for coarse pottery, bricks, tiles, paving blocks, clay lumber, sewer pipe, drain tile, railway ballast, and various other marketable products.

III. SEDIMENTARY ROCKS CHIEFLY OF ORGANIC ORIGIN

I. CALCAREOUS

To this sub-group belong rocks composed wholly or mainly of calcium carbonate. The primary source of the lime of limestones is the igneous rocks. In the weathering of igneous rocks containing lime-bearing minerals such as plagioclase feldspars, amphiboles and pyroxenes, the carbon dioxide of the atmosphere unites with the lime of the mineral forming the bicarbonate of calcium. This is carried in solution to the rivers, and by the rivers to the sea, where it changes to the common calcium carbonate.

The weathering of limestones and other calcareous rocks, also furnishes calcium carbonate to the rivers and ultimately to the sea. Many marine and fresh-water animals require calcium carbonate for their shells and other hard parts, and they have the power to separate it from the water for this use. At the death of the animals these hard parts accumulate in large quantities at the bottom of the comparatively shallow shore waters. Waves dash them to and fro along the beach, breaking and grinding many of them into a mass which forms the matrix for others. In this way immense deposits of calcareous detritus are formed, and subsequently solidified into limestone. In some cases the materials were completely ground up before burial; in others, perfect shells and other parts lie in a matrix of fine texture. Occasionally a very large proportion of the rock consists of almost perfect shells. Many limestones have undergone changes which have destroyed the fossils and left the rock evenly granular, with few or no traces of organic remains. Shells composed of aragonite (a form of calcium carbonate) disintegrate more readily than those composed of calcite—the commoner form of calcium carbonate.

LIMESTONE is a general name for solid rocks composed mainly of calcium carbonate. They differ widely in texture, hardness, purity, and the extent to which they show their organic origin. Some are coarsely crystalline and break with an uneven, granular surface; while others are amorphous and dense, and break with a smooth, conchoidal fracture. The hardness varies with the degree of consolidation and the purity. Pure limestones are readily scratched with a knife, but siliceous and dolomitic limestones are harder and not so readily scratched. The common impurities are sand, clay, silica deposited from solution or derived from silica-bearing organisms, iron carbonate, magnesium carbonate, iron oxides, and carbonaceous matter, such as bitumen. Pure limestones are readily soluble with éffervescence in acids, but impure limestones are not so readily soluble. In color they vary from white to gray, buff, bluish-gray, brown and black. The specific gravity ranges from 2.6 to 2.8.

VARIETIES: *Lithographic Limestone* is named from its use in lithography. The essential qualities are: uniformly fine texture, freedom from seams, veins, and inequalities of all kinds.

It must be soft enough to take the engraver's tool, and porous enough to absorb the grease which holds the ink. The stone should be low in impurities, which are insoluble or slowly soluble in cold acids, as they cause unevenness in the etched surfaces when the stone is prepared for printing.

Hydraulic Limestone is one which when burnt yields a lime or cement which will "set" or harden under water. This property is due to the presence of clayey impurities (alumina and silica), which unite with lime and water, forming calcium aluminates and calcium silicates. The rock is usually of a gray, bluish-gray or brownish-gray color, of fine texture and somewhat shaly appearance. The cement made from it is called "natural rock cement," or sometimes "hydraulic lime."

Dolomite, Dolomitic Limestone, Magnesian Limestone: These names are applied to limestone containing magnesium carbonate. Strictly speaking, dolomite should have the composition $CaMg(CO_3)_2$ or $CaCO_3.MgCO_3$, which is equivalent to $CaCO_3$ 54.35 per cent and $MgCO_3$ 45.65 per cent. A dolomitic limestone or a magnesian limestone might have the two carbonates in any proportion up to that of true dolomite. But as rock names the three terms are used interchangeably, with little reference to the percentage of magnesium carbonate.

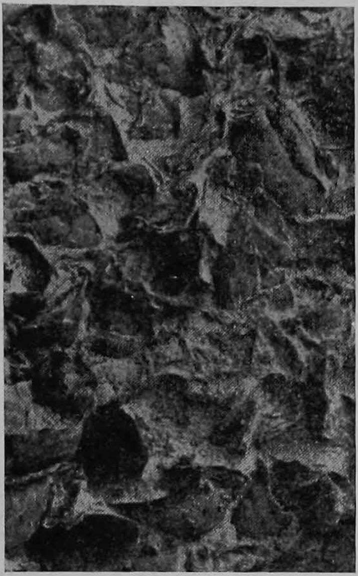
True dolomite is harder, of higher specific gravity, and less readily soluble in acids than pure limestones. It is more generally crystalline, and perhaps more commonly porous, than pure limestones. The lower the percentage of magnesium carbonate in the rock, the harder it is to distinguish the dolomitic limestones from others, even by the chemical test. In color, texture and other features they closely resemble pure limestones. Comparatively little dolomite was deposited as such. Nearly all of it is the result of a chemical change in which the magnesium chloride of sea water reacts with the calcium carbonate of common limestone. The magnesium replaces a part of the calcium as shown by the following equation:

$$2CaCO_3+MgCl_2=CaMg(CO_3)_2+CaCl_2.$$

Crystalline Limestone is one in which the calcium carbonate is crystallized into grains of calcite.

Amorphous Limestone is one in which the calcium carbonate is in a finely divided, non-crystalline state.

Bituminous Limestone is one containing more or less bituminous matter, probably derived from petroleum by oxidation.



Shell limestone

Shell limestone

Skeletons of minute animals in chalk. Enlarged

Crinoidal limestone

SEDIMENTARY ROCKS

Argillaceous Limestone is one containing an appreciable amount of clay.

Sandy or Arenaceous Limestone contains sand as an impurity.

Crinoidal Limestone is one composed largely of crinoid fragments.

Coral Limestone is one composed largely of coral and coral detritus. Coral sand is unconsolidated coral detritus.

MARL is a soft, earthy deposit, consisting of more or less disintegrated shells and other calcareous matter, with varying proportions of clay, sand, and often iron oxides and organic matter. It varies in color from ash-gray to yellow, brown and black. It is formed mainly in lakes and other inclosed waters.

Shell Marl is one in which shells or fragments of shells form a considerable proportion of the rock.

Freshwater Limestone may be regarded as a consolidated marl.

CHALK is a soft, friable rock, composed wholly or largely of the shells of foraminifera, such as textularia and globigerina. The broken or ground shells furnish a paste or matrix in which the more perfect ones are bedded. Sponge spicules, diatom shells (silica), and fragments of larger shells are generally present. In some cases sand is rather abundant. The common color is white or gray, but bluish, brownish and even black chalks occur. The chert and flint nodules so common in chalk are formed from the siliceous material of sponge spicules, radiolarian and diatom shells.

USES OF LIMESTONES: Limestones are the most generally useful sedimentary rocks. They have a very wide use as building stones, for which many of them are admirably suited, owing to the ease with which they may be quarried and shaped, and their strength and durability. They are practically the only source of lime, and are indispensable in cement manufacture. In the smelting industry large quantities are used for fluxing. A pure limestone is extensively used in sugar-refining. Marble, a metamorphic limestone, is used for building, decorating and sculpture.

The principal uses of chalk are for cement and lime manufacture. Whiting is finely ground chalk used in putty, and for scouring and polishing.

Magnesian limestone is extensively used in the manufacture of lime. Magnesian, or dolomitic marbles, are not uncommon.

Highly calcareous marls are used in the manufacture of cement, and as fertilizers. (See the section on Materials of Cements, Limes and Plasters.)

2. CARBONACEOUS

To this group belong those rocks composed in large part of carbon, derived from plant and animal matter, in a more or less mineralized form. Under favorable conditions, immense accumulations of vegetable matter are formed in swamp areas, and are preserved from complete decay by a covering of water, and later by burial beneath rock. The plant matter undergoes a slow chemical change by which the proportion of carbon is increased and the proportion of the other elements is decreased.

Depending upon the degree of change from vegetable tissue to mineral matter, these rocks form the series: *Peat, Lignite, Black Lignite, Bituminous Coal, Anthracite or Hard Coal, Carbonite or Graphite.* They are more fully described as economic minerals.

NATURAL GAS is a gaseous hydrocarbon compound occurring in much the same way as petroleum, and generally associated with it.

PETROLEUM, *Coal Oil, Mineral Oil*: These names are applied to liquid hydrocarbons occurring almost exclusively in porous sedimentary rocks. The oil itself was derived by a process of distillation from organic remains contained in the porous strata or in associated rocks. Petroleums differ widely in specific gravity, color, chemical composition, and consequently in the uses to which they may be put.

SOLID AND SEMI-SOLID HYDROCARBONS: These are substances resembling petroleum in composition, but of greater density. Many of them are residues derived from petroleum by oxidation and evaporation. They occur mainly in veins and porous rocks. The veins fill openings through which the petroleum welled up from the reservoirs at greater depth. Some of the more important solid and semi-solid hydrocarbons are: gilsonite, asphalt, grahamite, wurtzilite, albertite and ozokerite. They vary in color from gray or white to yellow, brown and black. Some are brittle at ordinary temperatures, while others are plastic. The lusters range from dull and earthly to brilliant. These are more fully described elsewhere.

3. SILICEOUS

The rocks of this group are composed mainly of silica derived from, or deposited by the aid of, plants and animals. Some of the rocks are made up of the hard parts of such organisms; some contain these hard parts and silica deposited from solution; while others are composed almost entirely of silica deposited by the aid of these organisms.

GEYSERITE, *Siliceous Sinter*: This is more or less pure silica deposited from the waters of hot springs or geysers. In many instances deposition is aided by minute algæ, which have the power to separate silica from waters carrying it in solution. The loose, spongy masses of geyserite characteristic of the geyser cones of Yellowstone Park are, in large part, due to the depositing work of these algæ. Siliceous deposits resulting from evaporation alone are harder and denser. The rock varies in color from white to gray, yellow and brown. In the areas of active deposition by algæ, very beautiful tints of yellow, green, red and brown are common, but as the mass becomes old it fades to gray or yellowish white.

DIATOMACEOUS EARTH (*Infusorial Earth*): This is a soft, whitish, grayish or brownish, earthy rock composed wholly or in large part, of the siliceous shells of minute, one-celled plants. These minute plants inhabit both fresh and salt waters, and deposits of their shells are found on the bottoms of lakes and oceans. Diatomaceous earth may be distinguished from chalk by its failure to effervesce in acid.

USES: There is a growing demand for clean diatomaceous earth for use as a filtering agent in sugar-refining and other industries; as an absorbent for liquid fertilizers, and disinfectants; in the manufacture of glazes, artificial stone, water glass, certain cements; as a base for certain pigments; as a sizing for paper; as a scouring powder, etc. It has been used as an insulating material for boilers, sound-proof partitions, floors, etc. It has been used as an absorbent for nitroglycerine in the manufacture of explosives.

Colorado occurrence: A small deposit occurs near Denver.

Siliceous Ooze, Radiolarian Ooze, is similar to diatomaceous earth, but consists of radiolarian and diatom shells, and occurs only on deep ocean floors.

FLINT, CHERT, *Hornstone,* are probably sometimes purely chemical in origin, but they are so commonly associated with organic processes that they are best classified with rocks of organic origin.

FLINT occurs as nodules and concretionary masses in chalk and limestone. In some cases it was deposited with the containing rock, but in others the nodules were formed later. Sponge spicules and silicified fragments of crinoids and shells are sometimes bedded in the nodules. It is a very dense, dark brownish-gray to gray rock, composed of very finely crystalline and amorphous silica, and having a splintery conchoidal fracture.

Uses: Flint pebbles are used as an abrasive material in tube mills and in other ways.

CHERT is an impure calcareous flint, usually of light-gray color. It will commonly effervesce when tested with acids.

Hornstone is similar to flint and chert.

TRIPOLI is the trade name of a porous, siliceous rock probably derived from the disintegration of chert. It is of white to pink color, and when firm and homogeneous is cut into filtering discs. The softer rock is finely ground and used for polishing powder.

4. PHOSPHATIC

PHOSPHATE ROCK, *Phosphorite*: This is a rock rich in calcium phosphate derived from organic remains. The bones of vertebrate animals and the shells and hard parts of a few invertebrates are composed largely of calcium phosphate. The excrement of vertebrates also contains calcium phosphate. The rock occurs in (a) well-defined strata alternating with limestone and other sedimentary rocks; (b) concretions and nodules, including coprolites; (c) earthy lenses and masses. The rock varies in color from gray to blue to white, buff, brown and black. In some cases it is dense and compact, but in others porous or even cavernous. Some deposits probably occupy the original position in which the organic matter was deposited, while others are the result of the solution of phosphatic material and its redeposition at lower horizons. In a few instances phosphate rock represents the replacement of calcium carbonate by calcium phosphate. Phosphate rock occurs in Florida, Tennessee, Alabama, the Carolinas, Idaho, Utah, Wyoming, and other states. It is extensively used in the manufacture of artificial fertilizers.

Guano is a phosphatic deposit composed mainly of the droppings of sea birds. It is also rich in nitrogen in the form of ammonium oxalate and urate. The phosphorus and nitrogen make it a valuable fertilizer.

IV. ROCKS CHIEFLY CHEMICAL PRECIPITATES

The rocks of this group are mainly simple chemical salts precipitated as a result of the concentration of solutions containing them.

ROCK SALT, *Halite,* is sodium chloride occurring in beds or strata. It is the result of the evaporation of saline waters in inclosed basins. Deposits of rock salt vary in thickness from an inch or two to over 4,000 feet (Sperenberg and Galicia). Since the sodium chloride of sea water is only about nine-tenths of 1 per cent of the volume of the water, it is evident that the volume of water evaporated must be about 112 times the volume of the salt deposited. Such a volume could be provided only by periodic or constant inflow from the sea to take the place of the water lost by evaporation.

Pure rock salt is clear and colorless, but most deposits are somewhat colored by iron salts or other impurities, such as clay. It has a specific gravity of 2.5 and is very soluble. Other salts—such as gypsum, anhydrite, carnallite, etc.—are commonly associated with it. Rock salt is abundant in New York, Michigan, Louisiana, Kansas, Texas, and other states.

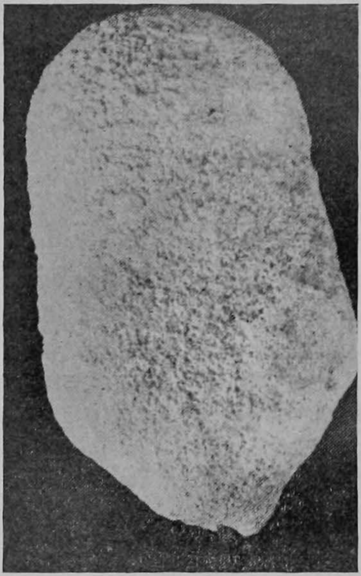
NATURAL SODA, *Trona, Urao,* is a mixture of sodium carbonate and sodium bicarbonate ($Na_2CO_3.HNaCO_3+2H_2O$). It occurs as a result of the drying-up of alkaline lakes, and is commonly mingled with clay and sandy sediments. It varies from white to gray and yellow, and from a loose, unconsolidated mass to a rather crystalline rock.

MIRABILITE, *Glauber Salt,* is a hydrous sodium sulphate ($Na_2SO_4+10H_2O$), which occurs chiefly in deposits resulting from the evaporation of soda lakes. When pure, it is white and transparent to opaque.

COLEMANITE, *Calcium Borate* ($2CaO.3B_2O_3.5H_2O$), is a colorless to milk-white, transparent to translucent mineral, occurring in crusts and strata, sometimes of considerable thickness. It is the result of the drying of alkaline lakes. The principal occurrences are those of the desert region of California, where it is extensively mined for the manufacture of borax.

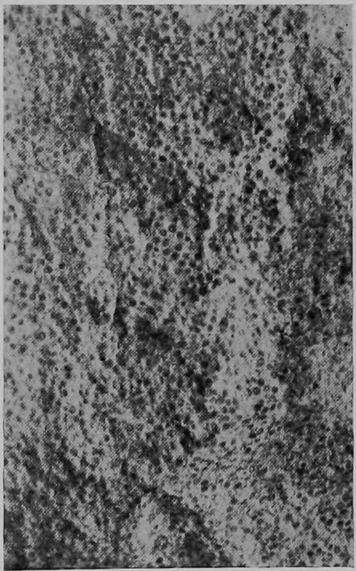
GYPSUM is the hydrous sulphate of calcium ($CaSO_4+2H_2O$). It occurs in strata in sedimentary rocks, and is generally a chemical precipitate resulting from the evaporation of inclosed sea waters or

Travertine



Travertine deposited on nail

Geyserite



Siliceous oolite

SEDIMENTARY ROCKS

salt lakes. A few small deposits are due to the action of sulphuric acid upon limestone; and the hydration of anhydrite may be responsible for a small amount of gypsum. The color varies from pure white to gray, brown, pink and black. Massive gypsum is generally distinctly granular. It is so soft as to be easily cut with a knife. The strata vary in thickness from a few inches to twenty, thirty or forty feet. It occurs at many points both east and west of the mountains in Colorado.

TRAVERTINE, *Calcareous Sinter, Calcareous Tufa,* is calcium carbonate rock, varying in color from white to gray, yellow and brown, and in hardness from loose, spongy masses to firm, granular or fibrous rock resembling common limestone. It is deposited from waters carrying it in solution, sometimes by purely chemical processes, and sometimes by the aid of minute algæ which have the power to separate it from the water. It is common about springs and hot springs whose waters pass through limestone or rocks rich in calcium carbonate. Immense deposits occur at Mammoth Hot Springs, in Yellowstone Park. The loose and spongy varieties often deposited about vegetation, and frequently having a rude fibrous appearance, are known as calcareous tufa or calcareous sinter.

ONYX (calcareous), *Mexican Onyx, Onyx Marble,* is a dense, banded travertine in which the bands are variously tinted, chiefly by metallic oxides. It occurs in Mexico, Arizona, California, Virginia, Utah, Colorado, and elsewhere, and is much used for decorative work instead of true marble.

Stalagmite and Stalactite: Caves in limestone regions are frequently made remarkably beautiful by deposits of calcium carbonate on the floors, walls and roofs. Those on the floor are formed by the deposition of the calcium carbonate carried in waters dropping from the roof and walls, and are called stalagmites. Those hanging like icicles from the roof and walls are called stalactites, and are formed by the evaporation of calcium carbonate-bearing waters seeping through the roof and walls. Cross-sections of stalactites usually show a radial, fibrous structure. The calcium carbonate is commonly in the form of aragonite.

Oolitic Limestone, Oolite: The rock is composed wholly, or in large part, of spherical concretions of lime carbonate built up in concentric layers or shells around centers or nuclei consisting of sand grains, fragments of shells, or other substances. In some cases the oolites are bedded in a calcareous matrix several times their volume; in others the rock is composed entirely of oolites cemented together in the process of growth. The grains vary in size from the diameter of a pin to that of a large pea. Beach sands washed by waters charged with calcium carbonate are left exposed to the air with a film of water surrounding them. As the water evaporates, its calcium carbonate is deposited as a film over the sand grains. The process is repeated again and again, as the grains are rolled backward and forward on the beach, and the oolites are built up. In some instances minutes plants (algæ) play an important part in the deposition of the calcium carbonate. Oolite sands are now forming along the shores of Yellowstone Lake and the Great Salt Lake. Oolitic limestone forms thick strata at various points in the Mississippi Valley, particularly in Iowa, where it is quarried for building stone at Marshalltown.

JASPER is a dense silica rock, commonly extremely, finely crystalline, and usually colored yellow, brown or red by iron oxide. It is a chemical precipitate, and in places, as in the Lake Superior iron ranges, forms thick bands and strata.

NOVACULITE, *Arkansas Stone,* is a very dense silica rock, breaking with a smooth, conchoidal fracture. It is white to gray and yellowish-gray in color, and in thin slivers is translucent. The microscope shows that some of it is fine-granular. Its mode of formation is unsettled. It occurs in Arkansas and is used for hones and whetstones.

Siliceous Oolite resembles oolitic limestone, and is like it in origin, although some is probably derived from oolitic limestone by the replacement of calcium carbonate by silica.

Iron Ores: These are fully discussed under economic minerals. They frequently form strata of considerable thickness and wide extent, as in the various iron ranges of the Lake Superior region, and in the Paleozoic rocks of the Appalachian area.

Alkali: See page —.

METAMORPHISM, AND METAMORPHIC ROCKS

1. WEATHERING.
2. METAMORPHISM (RESTRICTED).

1. The rocks of the surface of the earth are constantly subject to the operation of a set of forces which cause their disintegration and decay, and the formation from them of the materials out of which sedimentary rocks are made. These processes of change are included under the term *weathering.*

2. At a moderate distance below the surface another set of forces is more effective in causing, not disintegration and decay, but the rearrangement of materials, new textures, new mineral and chemical compositions, and new structures in both sedimentary and igneous rocks. These processes are known as *metamorphism* (in the restricted use of that word), and the rocks so changed are *metamorphic rocks.* (In reality, any natural process which profoundly changes the character of a rock, whether weathering or otherwise, is metamorphism.)

Metamorphism in this restricted sense is commonly divided into:

a. CONTACT METAMORPHISM.
b. REGIONAL METAMORPHISM.

a. CONTACT METAMORPHISM embraces those effects produced by the contact of molten rock with solid rock matter. The extent of these changes depends upon the conditions of temperature, moisture, pressure, and others under which the contact occurs. The rocks into which intrusion takes place may undergo changes of texture, chemical and mineral composition, a change from the crystalline to the non-crystalline form, or from the non-crystalline to the crystalline. The effects upon the intruded molten mass will, in the main, depend upon the same conditions.

Along the contact zone there may be partial or complete fusion of the wall rock, and a mingling of this with the intruded rock, forming a band quite unlike either of the original rocks. In the case of intrusion into sedimentary rocks, pure quartz sandstones may be changed into quartzites, or into dense flinty hornstone, showing no trace of the original sand grains. If the sandstone is impure with clay or calcareous material, various metamorphic minerals may be developed, such as garnet, wollastonite, feldspar, mica, and others. Or, on the other hand, the whole mass may be converted into a dense hornfels, or a rock called porcellanite. Clay rocks may be hardened into argillite, or baked into porcellanite, or slagged into a mass resembling an overburnt brick. Or, under other conditions, the rock may be partially crystallized. Pure limestone is frequently converted into white marble, while impure limestones may form mottled and banded marbles of various colors. In the case of small intrusions, the intruded rock along the immediate contact will be quickly chilled and solidified into a fine-grained rock, not infrequently partly glassy, while that in the center of the mass may be completely crystallized, and even show a coarse texture. Gases, vapors and waters charged with various mineral substances commonly accompany intrusions and frequently add special features to the mineral composition along the contact zone. Fluorite, tourmaline, beryl, and a number of other minerals occur in this way.

b. REGIONAL METAMORPHISM includes those changes brought about in large areas mainly as a result of heat, pressure and movement. Deeply buried rocks are subjected to enormous pressure, frequently at depths where the earth's heat is very high. When mountain-making movements take place, the mechanical stresses develop great heat, and the movement causes shearing and lamination. The results are frequently shown in more or less perfect lamination of the rock, accompanied by a rearrangement of the minerals with their longer dimensions parallel. Segregation is also common, and mica and other minerals are found partially or completely grouped in certain planes by themselves. Rocks composed almost entirely of one kind of mineral, such as the limestones and sandstones, rarely develop true lamination, although shear planes may be so prominent as to cause easy splitting in certain directions. Among the rocks resulting from regional metamorphism are gneisses, schists, quartzites, slates, crystalline limestones, marbles, dolomite, dolomitic marbles, serpentines, ophicalcites, and others.

Metamorphic rocks may be classified as follows:

I. METASEDIMENTARY (DERIVED FROM SEDIMENTARY ROCKS).
  a. Derived from sands and gravel rocks.
  b. Derived from clay rocks.
  c. Derived from calcareous rocks.
  d. Derived from carbonaceous rocks.

II. METAIGNEOUS (DERIVED FROM IGNEOUS ROCKS).
  a. Derived from rocks rich in feldspar (and quartz).
  b. Derived from rocks in which ferromagnesian minerals are dominant.
  c. Derived from fine-grained rocks of any mineral composition.

But such a classification assumes the possibility of determining the origin of the metamorphic rock. As this is frequently impossible, a simpler classification, based partly upon composition and partly upon structure, will be used.

A. FOLIATED.
  1. GNEISSES, GNEISSOID GRANITES, GNEISSOID SYENITES, ETC.
  2. ARGILLITES, OR SLATES, AND PHYLLITES.
  3. SCHISTS.
    a. *Mica and Chlorite Schists.*
    b. *Talc Schists.*
    c. *Hornblende Schist.*

B. NON-FOLIATED.
  1. QUARTZITE.
  2. MARBLE AND CRYSTALLINE LIMESTONE.
  3. SERPENTINE AND SOAPSTONES

A. FOLIATED

1. THE GNEISSES

The gneisses include those imperfectly foliated rocks in which the component minerals are more or less segregated and arranged in interrupted or discontinuous laminæ. The segregations and lamination are in some instances due to the conditions under which the rock solidified from the molten state, but in a greater number of cases they are the result of the operation of forces of regional metamphorism acting upon the rock after its solidification. The term ''gneiss'' was originally applied to a more or less laminated rock of the mineral composition of granite, and it is still sometimes used in that way. But it is now more commonly used as a structural term and applied to rocks of widely varying mineral composition.

GRANITE GNEISS is a gneiss of the mineral composition of a granite. It may have been derived by regional metamphorism from a granite or from a feldspathic sandstone (granitic sandstone or arkose). Highly quartzose sandstones yield *Quartzite Gneiss.* Conglomerates yield *Conglomerate Gneiss.*

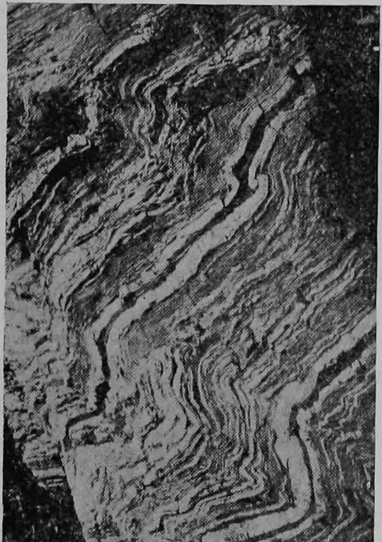
SYENITE GNEISS is one having the mineral composition of syenite. As sandstones of the syenite composition are almost unknown, it is probable that syenite gneiss is almost always derived from syenite.

MONZONITE GNEISS is one having the composition of monzonite, and is probably always derived from monzonite.

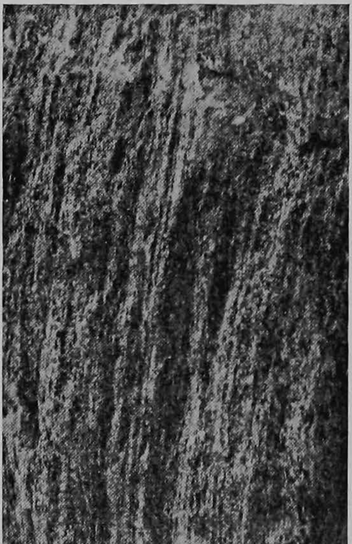
DIORITE GNEISS, GABBRO GNEISS, PYROXENITE GNEISS, PERIDOTITE GNEISS, need no special definition. Most of the gneisses named from some prominent mineral—such as *Hornblende Gneiss, Pyroxene Gneiss, Biotite Gneiss,* and others—can be properly placed

Gneissoid granite

Foliated gneiss



Banded gneiss



Biotite schist

METAMORPHIC ROCKS

under the types already described. A few rare gneisses—such as *Cordierite Gneiss* (one containing cordierite, iolite or dichroite). *Chlorite Gneiss* (one rich in chlorite, probably derived from biotite or hornblende), *Sillimanite Gneiss* (one rich in sillimanite or fibrolite), *Epidote Gneiss,* and others—cannot be readily placed under any of the first group.

Augen Gneiss is one in which the segregation and foliation are in such form as to suggest eyes (German *Augen*). Not infrequently the center of the "eye" is a dragged and partly crushed feldspar or quartz grain, while the border is biotite or other platy mineral.

GNEISSOID GRANITE: The term is used in two ways: (1) for a granite showing an indistinct gneissoid structure, due to mild metamorphism; (2) for a granite in which the gneissoid structure is due to segregation and partial foliation during solidification. *Gneissoid Syenite* and *Gneissoid Diorite* are similarly used.

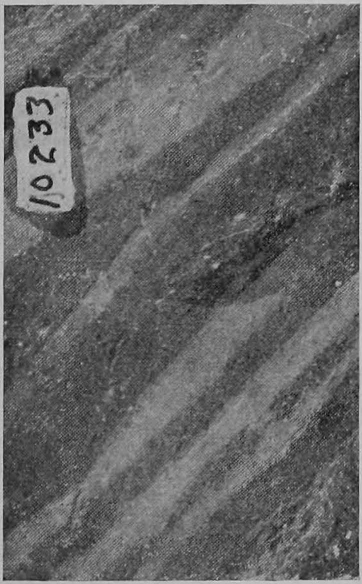
GRANULITE is a fine-textured rock, composed mainly of feldspar, quartz and garnets. One or more subordinate minerals—such as mica, augite, cyanite, rutile and tourmaline—are usually present. Feldspar is the most important mineral, and, as a rule, gives a grayish-pink color to the rock. The rock has a laminated or schistose structure, and a more or less complete segregation of the minerals into bands by themselves. It resembles aplites and felsites. The name "granulite" is also applied to rocks which have acquired a sugary, granular texture through crushing and movement.

2. ARGILLITE OR SLATE, PHYLLITE

These rocks represent stages in the metamorphism of clays, shales, and other fine argillaceous sediments. They are composed of extremely finely divided kaolin, fine grains of quartz, mica, feldspar, chlorite, calcite, rutile, pyrite, and other minerals. In the less metamorphic varieties the kaolin and the mineral grains are the original constituents of the clay rocks from which the metamorphic forms are derived, and in such cases the altered rocks belong to the metamorphic series because of their structure and the rearrangement of the mineral matter, and not because of any important new mineral or chemical composition. In the more completely metamorphosed slates, and in the phyllites, new minerals as well as new structures and new arrangements of materials occur.

The prominent cleavage or fissile structure of slates and phyllites commonly crosses the planes of bedding of the original clay

Slate



Phyllite

Biotite schist

METAMORPHIC ROCKS

rock, and is due to compression and not stratification. The planes of easy splitting are developed at right angles to the compression force producing them, and are due to a rearrangement of the mineral grains with their greater diameters in these planes. When the metamorphism is accompanied by the development of new minerals—such as mica, hornblende, and others—they are likely to be formed in similar parallel planes. As mica, hornblende and chlorite have prominent cleavage parallel to their longer diameters, it is evident that this mineral cleavage aids the rock cleavage. In a few slates the cleavage is parallel to the bedding or stratification.

CLAY SLATE is a clay rock in which compression and movements have rearranged the mineral grains into parallel planes, and developed the slaty structure and cleavage typical of slates, but have not caused important crystallization or the development of much new mineral. It is, as a rule, softer, less elastic and less durable than the mica slate. The color ranges from gray to black, brown, greenish and purple. The luster is sometimes pronounced, but is due to pressure and movement rather than to the development of mica.

MICA SLATE (Phyllite slate) is one in which much secondary mica has been developed. The structure, arrangement of materials, cleavage and other features are the same as those described above. It is harder, more elastic and more durable than clay slate. Its luster is due largely to the secondary mica. The colors are the same as those of the clay slate. The black color is commonly due to carbonaceous material, the green to chlorite, the purple to iron minerals, the red to hematite. The microscope shows that many mica slates contain from 35 to 40 per cent of mica, and from 30 to 45 per cent of quartz. Chlorite is commonly the next mineral in importance, but hematite, rutile, graphite and other carbonaceous matter are often important constituents. The full list of minerals found in slates would be very long and would include practically all those characteristic of metamorphic rocks. The mica of slates is mainly sericite, but biotite and others occur.

Uses: Roofing slate makes up about 75 per cent of the value of the slate production of the United States. Mill stock includes blackboards, school slates, flooring, wainscoting, mantels, hearths, switchboards, vats, sinks, laundry tubs, sanitary ware, dough troughs, flour bins, grave vaults, shelves, tops for laboratory, billiard and kitchen tables.

A part of the waste from slate quarries is used for road material and flagging, and a small part is ground and used as a mineral pigment. Slate veneer, a built up material, is recommended for roofing.

PHYLLITE (*"leafstone"*) may be regarded as a slate in which a highly perfect cleavage has been developed through the formation of a large amount of mica, especially along the planes of fissility. The mica is usually sericite and often gives a silvery luster to the fresh cleavage surfaces. Between these planes, in which the mica is so richly developed, other mineral matter may predominate. As a rule, the phyllites are more perfectly crystallized than the slates, and may be said to represent a more perfect metamorphism, and to form a connecting link between the slates and the schists.

Metaigneous Phyllites: Many phyllites are derived from fine-grained igneous rocks (such as rhyolites, andesite, phonolites, trachytes and the corresponding tuffs), by intense metamorphism, accompanied by shearing and a more or less perfect lamination. (Shearing is movement along certain parallel planes as a result of pressure or compression acting in such a way as to cause partial rotation within the rock mass.)

Porphyroid is a metaigneous phyllite derived from porphyritic, felsitoid rocks. It shows evidences of their original porphyritic texture in fairly well-preserved phenocrysts of quartz, feldspar and occasionally other minerals.

3. SCHISTS

In structure the schists are closely related to both slates and gneisses, and, like them, may be derived from both sedimentary and igneous rocks. They show a coarse texture and a more complete crystallization than the slates. The variety of minerals which may appear in schists is greater than that in slates, and the segregation of the minerals into planes by themselves and their parallel arrangement are more complete than in either slates or gneisses. The schists split more easily than the gneisses. The proportion of secondary minerals is commonly greater than in the gneisses, and the lamination is generally more perfect. Feldspar is less common than in the gneisses. Secondary mica, secondary hornblende, talc and chlorite form the principal minerals of as many important varieties of schist. The less common metamorphic minerals—such as garnet, staurolite, fibrolite, chiastolite, cyanite, tourmaline, graphite, cordierite, and others—sometimes occur in such abundance as to form distinct varieties of schist.

MICA SCHIST is one in which mica is the most characteristic mineral. When the mica is biotite, the rock may be called *Biotite Schist;* when it is muscovite, *Muscovite Schist.* Sericite gives *Sericite Schist.*

HYDROMICA SCHIST is a general or field name for fine-textured mica schists characterized by one or more of the white or light-colored micas, such as sericite and paragonite. Quartz, hornblende, feldspar, and one or more of the less important secondary minerals—such as garnet, staurolite, and others—are generally present. The color of the rock is determined chiefly by the variety of mica present. The rock splits easily along the planes in which the mica is segregated, and as very little other mineral appears on the split surfaces, the proportion of mica often appears greater than it really is.

USES: Fine-textured mica schists are used for whetstones.

Biotite-Sillimanite Schist is one in which sillimanite (fibrolite) is an important mineral. As it occurs in the Georgetown area, the rock consists of biotite, quartz, feldspar (orthoclase and plagioclase), and sillimanite in nearly equal amounts. Muscovite, garnet, tourmaline and corundum are prominent locally. The rock is probably of sedimentary origin.

TRANSITIONS*:* By the increase of quartz, and the corresponding decrease of mica, there is a transition to micaceous quartzite and quartzite. The Algonkian areas along the eastern foothills at Coal Creek, South Boulder Creek, the Big and Little Thompsons, and northward furnish beautiful examples of the passage from mica schist to quartzite.

The original sedimentary rocks varied in character from clays or shales to clayey and slightly feldspathic sandstones and pure sandstones. The former gave the mica schists, and the latter the quartzites, while the intermediate varieties gave the mica-quartz schists, the quartz-mica schists, and the micaceous quartzites. The calcareous mica schists are derived from calcareous clay rocks. Transitions from the finer mica schists through the phyllites to the slates are not uncommon. Good examples are to be found in the areas of contact metamorphism in Gunnison County. Transitions from granite gneisses to mica schist are common in metamorphic areas along the mountain ranges of Colorado, especially where crushing, shearing and other movements were profound. In the Lake Superior region volcanic tuffs have yielded good examples of mica schist.

Chlorite Schist is one in which chlorite is the characteristic mineral. The chlorite is commonly derived from biotite or one of the other dark minerals. The other minerals of chlorite schists may be practically the same as those of mica schists. It is more than probable that some chlorite schists were derived from clay rocks by the formation of biotite, and possibly hornblende, which, by alteration, yielded the chlorite. Others show evidence of having been formed from basalt, dolerite, gabbro, and other basic rocks. The color is generally a dull, earthy green.

GREENSTONE SCHIST: In the Lake Superior region and elsewhere, ancient diorites, basalts, diabases, gabbros, and other rocks rich in the ferromagnesian minerals, have been altered into what are commonly called ''greenstones''—rocks of dull-greenish color, rich in chlorite derived from pyroxene, amphibole, biotite and other minerals. In some of these ''greenstones'' movement and compression have developed a pronounced schistose structure. In cases where it is impossibde to decide from what rock the, schist was derived, the name ''greenstone schist'' is used; in others, the schist is named from the original igneous rock, as *Diabase Schist, Gabbro Schist,* and so on.

TRANSITIONS: Weathered mica schists and hornblende schists frequently show a considerable development of chlorite from the mica and the hornblende. The chlorite of chloritic slates is probably also secondary. It is very likely that many chlorite schists are derived from other schists by alteration. Transitions from greenstone to greenstone schist occur.

Talc Schist is one in which talc is present in sufficient amount to give the rock a soft, greasy feeling. The commonest color is pale greenish-gray, but darker colors occur. The talc occurs in mica-like flakes and grains having a good cleavage, but the plates are not elastic or springy like those of mica. Quartz, mica, feldspar, and other minerals common to schists, occur. As talc is a hydrous magnesian silicate, it is evident that the talc schists were derived from rocks containing both magnesium and silica. Siliceous dolomite and rocks rich in hornblendes and pyroxenes low in iron are probably the sources of talc schists.

Hornblende Schist, Amphibolite: This sub-group of the schists includes a number of varieties in which the amphiboles are the characteristic minerals. Orthoclase, plagioclase, biotite (less commonly muscovite), quartz, pyroxenes, garnet, pyrite, magnetite, and other minerals common to metamorphic rocks, occur in varying amounts. They are common rocks in most of the metamorphic areas of Colorado and other parts of the country. In texture they range from those in which the main minerals are readily recognized without a lens, to those in which it is difficult to determine the minerals even with a strong lens. The segregation of the different minerals into planes by themselves frequently makes the naming of the rock easy.

They sometimes form large bodies of rock, but more frequently occur as bands and lens-shaped masses, associated with other schists and gneisses, into which they sometimes grade. In some cases their relations to the rocks with which they occur leave little doubt that they were derived from basic igneous rocks, such as diorites, gabbros, peridotites, and others. The pyroxene of the gabbros and peridotites has been changed to amphibole. Again, they are found in such relationships, and of such mineral and chemical composition, as to make it clear that they were derived from very impure limestones, or from calcareous clay rocks. It seems desirable to call the less schistose types amphibolites.

Alteration: The hornblende and biotite alter to chlorite, and the rock becomes a chlorite schist. Serpentine is a common alteration product. The feldspar becomes kaolinized, and calcite, epidote, and other secondary minerals are formed. The iron minerals yield limonite, which gives the rock a brown, rusty appearance. In some places, as in the Front Range of Colorado, the amphibolites resist weathering remarkably well, and in many instances appear perfectly fresh even on exposed surfaces. This is true along the Clear Creek Canyon and in the Sangre de Cristo Range.

Varieties: *Actinolite Schist* is one in which the amphibole is principally actinolite. *Glaucophane Schist* has glaucophane for the amphibole. When it is possible to determine the rock from which the hornblende schist was derived, the terms *Diorite Schist, Gabbro Schist,* and so on, may be used. *Eclogite* is a hornblende schist composed in large part of hornblende, a green pyroxene (omphacite), garnets, cyanite, mica, and other less important minerals.

B. NON-FOLIATED

1. QUARTZITE

QUARTZITE is a metamorphic sandstone. The change has resulted in the almost complete filling of the intergranular spaces, and has bonded the grains together so firmly that the rock breaks as readily through the grains as around them or through the cementing material. The change may be produced in two principal ways: (a) Silica deposited from solution may completely fill the intergranular spaces and so strongly cement the sand grains together that it is practically a homogeneous mass. (b) Intense heat, accompanied by pressure, may so deform and compress the grains that they form a perfectly close-fitting mosaic, occupying the entire space. In some cases the rock is converted into a dense, flinty mass, showing no trace of the original grains, and breaking with a smooth, conchoidal fracture.

The impurities of the original sandstone will show in the quartzite formed from it. The metamorphism of a feldspathic sandstone may yield a feldspathic quartzite, or it may form a micaceous quartzite through the alteration of the feldspar to mica. A clayey sandstone may be changed into a quartzite in which biotite, muscovite, hornblende, feldspar, epidote, sillimanite, garnet and various other secondary minerals, may appear. The color varies from pure white to gray, brown, red, and even black. It depends mainly upon the impurities.

Varieties may be recognized and named from the prominent minerals other than quartz, as *Feldspathic Quartzite, Graphitic Quartzite, Micaceous Quartzite,* and others.

Oolitic Quartzite is one composed of oolitic grains built up by the deposition of chalcedonic silica around minute grains of quartz.

BUHRSTONE is a cellular rock composed of very dense siliceous material. It is probably derived from a fossiliferous limestone by the replacement of the lime carbonate by silica. The cells or cavities may represent leached-out fossils. They were formerly much used for flour-making. In Germany cellular basalts are used as buhrstones.

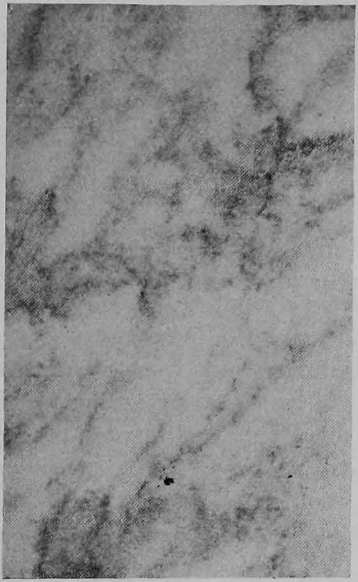
TRANSITIONS from quartzite to quartz schist, mica schist, slate, phyllite and gneiss are known.

2. CRYSTALLINE LIMESTONES AND MARBLES

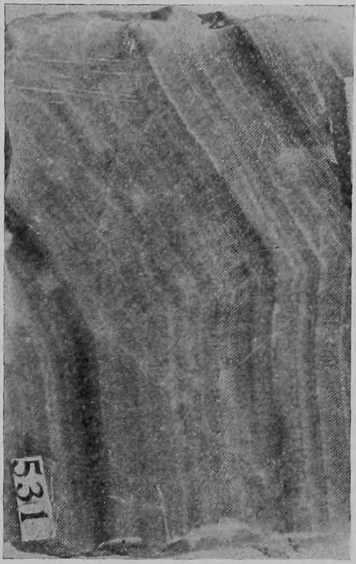
Crystalline limestones are common in regions where the associated rocks show little or no evidence of metamorphism. This is due to the fact that calcium carbonate shows a strong tendency to crystallize. As a consequence, when limestones charged with moisture (ground water) are subjected to the pressure of a considerable load of overlying rock, and the heat resulting from that pressure, their calcium carbonate and magnesium carbonate pass from non-crystalline to the crystalline form, while the impurities they contain may remain practically unchanged, and the associated rocks may show no evidence of metamorphism. Crystalline limestones thus formed are not (here) included with metamorphic rocks. But when the change has been so profound as to cause the crystallization of the impurities of the limestone and the development of new minerals from them, the rock must be called metamorphic. (In such cases the associated rocks will also show metamorphism.) The limestone becomes a mass of crystal grains, somewhat resembling loaf sugar. The size of the grains will depend upon the conditions under which they were formed. In some rocks they are so small as to be almost indistinguishable without the aid of a lens, while in others they may reach a diameter of a quarter of an inch or more. Whether such rocks are to be called marbles or merely limestone depends largely upon their beauty and purity of color, their closeness and uniformity of texture, and their suitability for ornamental work.

When pure limestones and pure dolomitic limestones undergo metamorphism, the most noticeable change is crystallization or recrystallization. No new structures are developed, but, on the contrary, old ones, such as bedding and lamination, are found frequently obscured or destroyed, and fossils may be partially or completely obliterated. The failure to develop lamination and cleavage is probably due largely to the fact that calcite, when subjected to stresses, especially in the presence of heat and moisture, will readily change its crystal form by molecular rearrangement. It is also worthy of note that rocks composed of a single mineral in grains whose length, width and thickness are about equal, are less likely to develop platy or schistose structure than are those containing several minerals of irregular sizes and unequal dimensions.

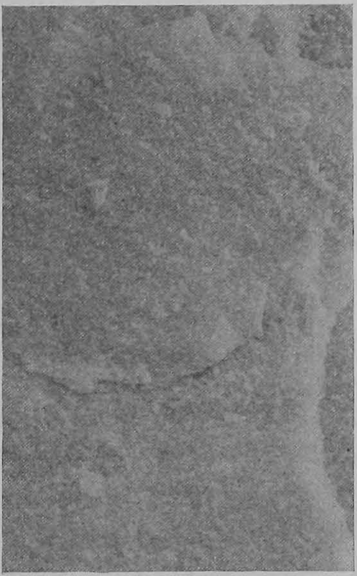
The commonest impurities of limestones are magnesium carbonate, silica, iron carbonate, iron oxides, organic carbon, and



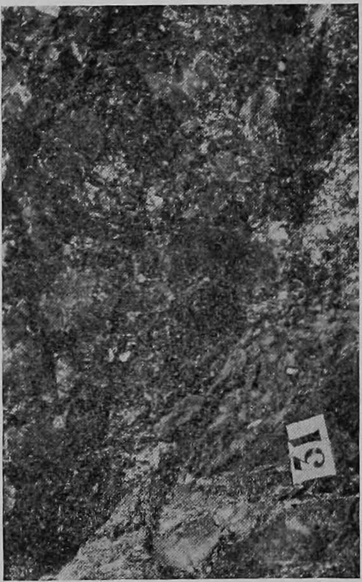
Mottled marble
Rutland, Vt.



Onyx marble
Arizona



Marble
Yule, Colo.



Metamorphosed breccia

METAMORPHIC ROCKS

clayey matter. The magnesium carbonate is usually combined with calcium carbonate in the form of the mineral dolomite $CaMg(CO_3)_2$. Rocks composed entirely of this mineral are known as dolomite. When calcium carbonate and the mineral dolomite are present in varying proportions, the rock is known as dolomitic or magnesian limestone. Silica may be present as sand grains or as a constituent of clay. Organic carbon is derived from plants or animals. Clayey matter adds to the rock, silica, alumina, and frequently other salts common to clays.

When limestones containing these impurities undergo metamorphism, the possibilities for the formation of new minerals are very large. Among the minerals so formed are varieties of amphibole (tremolite and actinolite), varities or pyroxene (wollastonite and diopside), varieties of mica (phlogopite and muscovite), varieties of garnet, varieties of feldspar (orthoclase and anorthite), serpentine, chlorite, scapolite, epidote, vesuvianite, graphite from the carbon, and apatite. On the outer borders of limestone masses, where they grade into calcareous clay rocks and sandstones, these secondary minerals may be developed in such quantity as to give character and name to the rock. But as such rocks are comparatively rare, they are not fully described here. Some of the commonest are: malacolite rock, augite rock, wollastonite rock and garnet rock.

Malacolite Rock is composed mainly of fibrous or granular malacolite, with more or less other mineral matter. It occurs with crystalline limestone.

Augite Rock is a granular rock composed mainly of augite, but generally accompanied by more or less tourmaline, apatite, titanite and scapolite. It is associated with limestone in the metamorphic rocks of eastern Canada.

Wollastonite Rock resembles marble, and in one or two places is quarried and used as marble, but it is distinctly harder, and on close examination shows many groups of needle-like or fibrous crystals of wollastonite. Calcite, diopside, hornblende and mica are other constituent minerals.

Garnet Rock occurs at the contact between intruded porphyry and a limey shale or impure limestone at several points in Arizona and elsewhere. It varies from almost pure massive garnet to a rock composed of grains and crystals of garnet in a complex matrix of the other minerals characteristic of contact zones.

MARBLES: In common usage the term "marble" includes all rocks composed largely of calcium carbonate or calcium-magnesium carbonate that will take a good polish and are suitable for ornamental work. No distinction is made between those marbles derived from magnesian or dolomitic limestones and those derived from pure limestones. The rock consists of grains of calcite, or of calcite and dolomite, and the various minerals derived from the impurities. The texture varies from fine to coarse, but is generally uniform in the same rock mass. The alteration is principally by solution, and the impurities, being less soluble than the calcium carbonate and dolomite, are left behind as a residual clay.

Pure limestones and pure dolomitic limestones form white marbles. Impure limestones of both kinds yield marbles in which the color and the distribution of color depend upon the nature and the final distribution of the impurities. Carbonaceous (bituminous) limestones yield blue, gray and black marbles. Ferruginous limestones yield gray, blue-gray, yellow, buff, brown and red marbles, depending upon the form in which the iron occurs. Green marbles, and the green banding and mottling of white marbles, may owe their color to the presence of serpentine, talc, chlorite, pyroxene or hornblende, while yellow tones may be due to epidote, iron oxides and titanite. Garnets, vesuvianite, phlogopite and other minerals may give brownish tones.

Varieties of Marble: Some varieties are named from the use to which they are put, while others are named on account of their composition or other characteristics.

Statuary Marble is a fine-textured, pure-white marble which will chisel satisfactorily, and will take a perfect and durable surface finish whether polished or dull.

Architectural Marbles are those whose color, texture, working qualities and strength suit them for architectural work.

Ornamental or Finishing Marbles are those which, on account of their beauty of color, color patterns or banding are specially adapted to decorative work.

Onyx Marble, Mexican Onyx, is a beautiful translucent rock, composed of calcite or aragonite deposited from solution in the form of travertine, stalactite or stalagmite. A beautiful color-banding marks the deposition of successive layers, and often forms attractive patterns in the cut stones.

Ophicalcite, Ophiolite, Serpentine Marble, Verd Antique, are various names for a marble-like rock composed of white or gray calcite or dolomite, or both, with a mottling of serpentine which may vary in color from yellowish-green to black. The serpentine is, in some cases, derived from the alteration of pyroxene formed by the metamorphism of an impure magnesian limestone.

Cipolin, Cipollino, is a marble rich in mica and sometimes talc. The mica may be irregularly scattered, or may be segregated in straight or wavy bands. Quartz, garnet, hornblende and other minerals may be present.

Ruin Marble is a fine-textured marble having an irregular angular pattern, due to the intersection of straight lines, which may represent the fractures of a healed brecciation. The angular blocks formed by the lines vary in color tone. It is sometimes called breccia marble.

Breccia Marble is a name commonly applied to a marbleized pebbly limestone conglomerate found in Maryland. It is also called "Potomac marble."

Shell Marble, Fossil Marble, is a crystalline limestone in which the metamorphism has not gone far enough to destroy the fossils. The cut and polished surfaces of the rock show the outlines and cross-sections of shells and other fossil remains. A red, marble-like limestone of this kind is extensively quarried in the Appalachian states.

Bird's-eye Marble is a variety of shell marble in which the patterns formed by the fossils on the cut surfaces suggest eyes. The fossils are chiefly crinoids and corals.

3. SERPENTINE AND SOAPSTONE

SERPENTINE ROCK: When basic rocks—such as hornblendites, gabbros, pyroxenites and peridotites—undergo alteration at or below the level of ground water, the principal secondary mineral formed is commonly serpentine. Occasionally the alteration is so thorough, and the removal of other mineral matter is so complete, that a mass of practically pure serpentine results. But very commonly cores and fragments of olivine, pyroxene, hornblende and biotite remain. Magnetite, chromite and garnets (pyrope) formed at the same time as the serpentine frequently occur as scattered grains in the rock. Seams or veinlets of calcite, magnesite and other carbonates are not uncommon. Talc and chlorite also occur. The alteration of hornblende schist also yields serpentine rock, but this is not an important source.

The rock varies in color from a pale yellowish-green to greenish-brown, dark green and almost black. Small masses of almost pure-white serpentine are occasionally found. The pure serpentine is easily cut with a knife, but silica deposited from solution frequently makes the rock rather hard. The texture varies from fine and dense to coarsely granular. Fibrous spots and bands are common, and veins of chrysotile (serpentine asbestos) furnish much of the so-called asbestos of commerce. The luster is dull and waxy or oily, and the rock varies from translucent to opaque. In structure the serpentine rocks vary from massive to platy and almost schistose.

USES: The rock is cut into slabs, polished, and used for interior decoration.

SOAPSTONE, *Steatite,* is a rock consisting chiefly of talc derived from the alteration of magnesian silicates or possibly siliceous dolomites. Quartz in scattered grains and veinlets, magnesite and chlorite are frequently present. The color ranges from white to gray and green. It is soft and easily worked, and finds many uses in commerce. It is often associated with serpentine, talc schist and chlorite schist.

BUILDING STONES

BUILDING MATERIALS IN GENERAL

The common building materials may be classed as natural and artificial. To the first class belong wood, stone and raw clay; to the second, brick, cement and iron. It is clear to every observer that the consumption of the forest timbers of the United States far outruns the supply by regrowth. It is evident, therefore, that with a rapidly growing population and a rapidly decreasing timber supply, there must come an increasing use of stone and artificial building materials. Of all building materials, stone is best suited to the main structural features of large buildings and great public works, because it alone has the qualities of strength, durability and dignity of appearance so generally sought in the erection of such structures. But many varieties of building stone are well adapted to the building of residences. And, for the laying of foundations, whether for buildings, or for bridges and other public works, stone will probably continue for some time to hold first place among building materials.

ESSENTIAL QUALITIES OF BUILDING STONES

The essential qualities of building-stones are: I, Strength; II, Durability; III, Workability; IV, Color and Beauty.

1. STRENGTH.
    - (*a*) Factors determining the strength of a stone and the permanence of its strength:
        - (1) Composition.
        - (2) Texture.
        - (3) Structure.
        - (4) Mode of aggregation, and cementing materials.
    - (*b*) Stresses considered.
2. DURABILITY.
   Agencies of disintegration and decay:
    - (*a*) Mechanical:
        - (1) Temperature changes.
        - (2) Water.
        - (3) Wind.
        - (4) Mechanical wear in duty.
    - (*b*) Chemical:
        - (1) Water.
        - (2) Atmospheric gases.
        - (3) Organic acids, etc.
3. WORKABILITY.
    - (*a*) Quarrying.
    - (*b*) Dressing.
    - (*c*) Polishing and decorative working.
4. COLOR AND FASHION.

1. STRENGTH

The strength of a stone is measured by its ability to withstand stresses. A stone in a wall is subjected to strains of various kinds. Of these, the most important are the crushing, the tensile, the transverse and the shearing stresses.

1. FACTORS DETERMINING THE STRENGTH OF A STONE AND THE PERMANENCE OF ITS STRENGTH:

- (a) Composition.
- (b) Texture.
- (c) Structure.
- (d) Mode of aggregation.

(a) *Composition*: The different minerals of which building-stones may be composed vary widely in hardness and resistance to crushing force. For example, quartz is harder and has a higher crushing strength than calcite or feldspar. It is harder, but has a lower crushing strength than hornblende. Again, different minerals have different coefficients of expansion under changes of temperature; and the stresses resulting from differential expansion and contraction are more important in a rock composed of several minerals than in a rock composed of only one. Some minerals, such as calcite and feldspar, have very pronounced cleavage; while others, like quartz, have little or none. Cleavage renders a mineral weaker in certain directions than in others.

The solubility of the materials of a rock is an important factor in the permanence of its strength. This is particularly true in the matter of the cementing material in sandstones and other clastic rocks, where the weakening or removal of the bond between the grains would leave a crumbling mass.

(b) *Texture*: Other things being equal, coarse-textured rocks are weaker than fine-textured rocks of the same composition. There is less interlocking of the component grains, more unoccupied space, and the contact planes between the minerals are distributed in fewer directions. The degree of porosity has an important bearing on the strength of a rock, and will be discussed more fully in another place.

(c) *Structure*: The structural feature of most importance in building stone is lamination. In igneous rocks such as granite, lamination may be due to:

(1.) Arrangement of the component minerals with their broader faces parallel.

(2.) The segregation of the component minerals in parallel bands.

(3.) Pressure and shearing, resulting in fissility or cleavage.

In sedimentary rocks the lamination is generally parallel to the bedding planes, and may be due to short pauses in the deposition of the rock, to slight changes in the composition, and to difference in texture of the material of the rock.

Stones showing a directional structure from any of these causes split more readily in one direction than in another. The ratio of absorption of water, coefficient of expansion, and the solubility are unequal in the different planes. Such stones are stronger and weather better when laid with their lamination planes in a horizontal position.

(d) *Modes of Aggregation of the Grains of the Rock*: There are three common modes of aggregation of the grains or component parts of rocks:

(1.) Chemical.
(2.) Crystal.
(3.) Cementation.

The chemical aggregation is exemplified by compact, non-granular limestones and by non-crystalline igneous rocks. The mass may be called amorphous or homogeneous. There are no directions of unequal strength or liability to disintegration. Granites are rocks showing crystal aggregation; the various mineral grains are intimately interlocked as a result of crystallization from the molten condition, and the bond is a strong one. The grains of sand in a sandstone are held together either by a cementing material or by simple pressure cementation. The commoner cementing materials are: silica, calcite, clayey matter, iron oxides. Of these, silica is the strongest and most desirable, because it is insoluble, free from cleavage, and has the same coefficient of expansion as the sand grains which it binds together. Calcite is soluble, has very pronounced cleavage, and has a different coefficient of expansion from that of the sand grains, all of which are elements of weakness. Argillaceous matter is liable to disintegration. Iron oxide, particularly hematite, makes a fair bond. Pressure cementation alone is rather uncommon, though it is believed to exist in some quartzites.

(2.) STRESSES TO WHICH BUILDING STONES ARE SUBJECTED. The crushing stress to which a stone would be subjected in the basal tier of a very high wall is far within the initial crushing strength of any stone which would be considered fit for building purposes. Merrill records the weight per cubic foot, and the crushing strength per square inch, of fifty-eight limestones from quarries in fifteen states. The lowest crushing strength recorded, 6,500 pounds per square inch, was that of a stone weighing 147 pounds per cubic foot. A one-foot course of this stone would exert a pressure of about one pound on each square inch of the surface on which it rested. If this stone were built into a wall of uniform thickness, the vertical strain would not be sufficient to crush the blocks of the basal course until the wall had reached a height of 6,500 feet.

Making a liberal allowance for the weight of inside structural parts, for roof and for the load the building might be expected to carry, it is evident that almost any stone which would stand quarrying and shipment would have a crushing strength high enough for perfect safety in all ordinary structures. Builders will rarely place a stone where the direct pressure upon it will exceed one-tenth of its crushing strength.

The tensile strength of a stone is its ability to withstand a pulling stress. It depends upon the cohesion of the particles of the stone, and has been discussed under "mode of aggregation." Stones in a wall are rarely subjected to direct tensile stress, but their ability to withstand transverse and shearing stresses depends largely upon their tensile strength.

Transverse stress is stress applied at right angles to the length of the block. The cracking of stone and brick walls is usually due to transverse stress resulting from unequal support throughout their length. This is also true in the cracking of a single block. In the cracking and separation of the two parts of a wall there is usually a component of tensile stress, but it is seldom great.

Transverse stress generally results from the settling of foundations or from the failure of the builder to give the stone uniform support from end to end. As shearing is a change in the form of a mass without change of volume, it is evident that the tensile strength is an index of the shearing strength, since no change of form can take place until the cohesion of the component particles of the rock is overcome—in other words, until the tensile strength is exceeded.

II. DURABILITY

The durability of a stone depends chiefly upon its ability to withstand the climatic conditions to which it is exposed. The principal agencies of disintegration and decay may be divided into two classes:

(1.) Mechanical, including: temperature changes, water, wind, mechanical wear in the place where it is used.

(2.) Chemical, including: water, atmospheric gases, organic acids, etc.

1. MECHANICAL AGENCIES:

(a) *Temperature Changes*: Change of volume in response to change of temperature is one of the most important causes of rock disintegration. It is more effective in crystalline rocks than in non-crystalline rocks of the same composition. The coarser the texture, the greater the strain. Rocks composed of several different minerals suffer more than those containing only one. A granite may contain quartz, feldspar and hornblende. The coefficients of expansion of these minerals are proportional to 36, 17 and 28, and as a result unequal stresses will be set up within the rock whenever expansion or contraction takes place in response to change of temperature. In a rock composed of but one mineral there is but one coefficient of cubical expansion, and the strain is more uniform. The larger the expanding grain, the greater will be the thrust in a given direction, and the greater will be the tendency to move the neighboring particles from their normal position. In other words, the coarser the grain of the rock, the greater the liability to disruption. For example, the directions of thrust are fewer and the thrusts are proportionately greater from a single grain of ten cubic centimeters than from ten grains of one cubic centimeter promiscuously arranged. The strain in the latter case is more equally distributed and, therefore, less destructive. For this reason fine-grained rocks suffer less than coarse.

The coefficient of lineal expansion of a mineral grain is different in the direction of the different crystal axes. Thus, quartz expands five and one-half times as much in the direction of the vertical axis as in a direction at right angles to that axis. Hornblende expands ten times as much in the direction of one of its axes as in that of another. These unequal expansions create similarly unequal stresses in the different directions.

A porous rock will probably suffer less from this force than will a compact one of the same composition, owing to the fact that a part of the expansion will be accommodated by the intergranular spaces. On the other hand, the area of intergranular contact is less in the porous rock, and consequently the work to be accomplished in separating the grains is less. In some parts of the United States the daily and seasonal range of temperature is very great, and changes are often very rapid. The particles of a stone are almost constantly acted on by this resistless force of expansion and contraction. The effects are much more marked on the south and west sides of buildings than on the north and east, owing to the fact that these sides are exposed to the sun during the hottest part of the day, and the changes of temperature are greater than on the other sides.

Stone is a poor conductor of heat, and under the influence of a midday sun the outer surface may be brought to a high temperature before the opposite side of the block has felt the effect of the sun. This causes a differential expansion which tends to weaken the stone. The north wall, not getting the direct rays of the sun, heats up more slowly and uniformly, and the resulting differential strain is much less. In winter the inside surface of a wall may have a temperature of 70° F. while the outside may be at —30°. The effects of this rapid and intense surface-heating are seen in the great talus streams of thin concavo-convex flakes and plates of rock which cover the slopes of many of our western mountains. A particularly good example of this is to be seen in the Dolores Peaks of Colorado. ''Shelling'' of the surface of rocks is a common phenomenon, and is due, in large measure, to expansion and contraction from surface heating. E. R. Buckley[1] says that in many of the limestone quarries of Wisconsin thin beds five to six inches in thickness, when first exposed to the summer's sun, become heated entirely through and arch up on the quarry floor, and generally break so as to be useless. In certain parts of India the quarrymen build a fire on the floor of the granite quarry, and, as the fire is moved slowly over the surface, a slab of stone of uniform thickness splits away from the underlying rock. The thickness depends upon the depth the heat penetrates, but slabs five to six inches in thickness and several hundred square feet in area are taken up in this way. The splitting is independent of the lamination of the rock.[2] A familiar method of breaking large boulders in this country is to build a fire over them, and, when they become intensely heated, dash cold water over them. In large fires, stone walls may become intensely heated. If water is turned on the hot stone, it splits in layers parallel to the outer surface. Under such conditions granite probably suffers most, and sandstone least, of the common building-stones. In the matter of durability of building-stones, when subjected to such heat tests as the burning of a large building, authorities differ widely, but there is a measure of agreement on the point that granite is about the least fire-proof of the common building stones. Limestones, dolomitic limestones and marbles suffer comparatively little up to a temperature of 900°-1000° F., providing they are not suddenly cooled. Above this temperature they are likely to be changed to quicklime, and slacked

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[1] "Building and Ornamental Stones of Wisconsin," p. 19.
[2] H. Warth, "Quarrying of Granite in India": Nature, June 17, 1895.

when exposed to moisture. The behavior of sandstones under similar tests is usually good, though sudden cooling with water seems to cause a greater degree of disintegration than in the case of limestones. The fire tests made by Winchell[1] on the Minnesota building stones would seem to place the sandstones and limestones in about the same rank. But it is open to question whether the sandstones tested—the Potsdam, the St. Croix and the Jordan—as fairly represent sand-rock building stones in general as the limestones tested—the St. Lawrence, the Shakopee, the Galena and the Trenton—represent lime-rock building stones in general.

(b) *Water*: As an abrading agent, water has very little effect upon the stones in the walls of buildings. River waters laden with sediments may, in time, cause appreciable wear on bridge foundations, but even here, except under rare conditions, the results are unimportant. But water within the stone may be the most powerful agent of mechanical disintegration to which building stone is exposed. All rocks are capable of absorbing water, but the amount depends upon the mineral composition and the porosity of the rock. Granite may absorb water to the extent of .37 per cent of its own weight; compact limestones, from .5 to 5 per cent; marble, about .3 per cent; and sandstones, from a very little up to 10 or 12 per cent. This water, apart from changes of temperature involving freezing, is quite unimportant as an agent of mechanical disintegration; but, in freezing, water expands about 9 per cent—100 volumes of water forming 109 volumes of ice. The force of this expansion is equal to a pressure of about one ton per square inch, and as it acts between the grains of the rock, its effect is to break the bonds holding them together, and so cause crumbling. It is a severe test of the tensile strength of a rock. Merrill[2] says: "No stone, however strong, can endure the enormous strain to which it would be subjected if frozen solid when holding any considerable amount of water within its pores."

But the destructive effects of freezing are not proportional to the amount of water a stone can absorb and retain. Much depends upon the character of the pores or openings containing the water, and upon the degree of saturation of the stone at the time of freezing. The ease with which water moves through a stone depends upon the size and continuity of the openings. The flowage in capillary tubes is proportional to the fourth power of the diameter, and this means that the flowage in one capillary tube would

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[1] "Geology of Minnesota," Vol. I, pp. 185, 196-203.
[2] "Stones for Building and Decoration," p. 438.

be sixteen times that in a tube of half the diameter. If two stones have the same percentage of porosity, but the openings in the one have a greater diameter and are more continuous than those of the other, the water in the first will move many times faster than that in the second, and, in freezing, a part of the expansive force will be spent in driving the water along the openings, and possibly out of the stone. In the second stone the water will be more likely to freeze in place, and much more of the force of expansion will be spent in pushing the grains apart. Again, the stone with the larger openings will lose its water by evaporation more readily than will the other, and it is therefore less likely to be destroyed by freezing, since the destructive effect depends largely upon the percentage of pore-space filled with water. If the pores are only partially filled, and there is ample room for the expansion of the water in freezing, comparatively little damage will be done. It must, however, be remembered that, while rocks with very small pores retain the absorbed water longer, they take it up much more slowly, and are less likely to become saturated with storm waters, than are those with larger pores. All things considered, it is well to avoid stones having a high absorption ratio, and especially if they are of fine texture.

Certain rocks contain measurable quantities of readily soluble salts; in others, such salts are formed by chemical reactions between some of the constituents of the stone and those of the atmosphere. Under ordinary atmospheric conditions, these salts are crystallized, dissolved, and recrystallized within the stone, and the mechanical strain accompanying the process loosens and separates the grains of the rock. This is a very important consideration in connection with the laying of foundations in alkali-rich soil. The ground water carries the salts into the stone, and, when the water evaporates, they crystallize with expansion, developing a force similar to that exerted by water in freezing.

Many minerals, when exposed to the action of water, become more or less hydrated. As a rule, this change involves change of volume, and as each mineral has its own ratio of expansion from hydration, and as some minerals are more likely to become hydrated than others, it is plain that the process of hydration will cause unequal stresses. The mechanical effect is similar to that of expansion from rise of temperature, but there is not the alternate expansion and contraction which accompanies temperature changes. The upper walls of a building are not likely to suffer appreciably from hydration, but the stones of the foundation may be saturated for long periods of time, and, as a result, become partially hydrated.

(c) *Wind*: Abrasion by wind carrying dust and sand is a matter of some importance in certain parts of Colorado. At Marshall there is a house built of the local Laramie sandstone, and said to be twenty-five years old. It is true the stone is of rather poor quality for building purposes, but it well illustrates the work of wind. The stones in the east and north walls still show the marks of the dressing-tool, while most of those in the west and south walls have not only lost all traces of the chisel, but have been cut down in places three-quarters of an inch, as is shown by the projection of hard seams of quartz which were undoubtedly level with the general surface of the stone when it was placed in the wall. The mortar is, in places, removed to a depth of an inch and a half. The hard, fresh dolerite of the Valmont Butte shows very pronounced erosion by the same agency. The surfaces of exposed boulders are covered with parallel grooves, many of which are nearly an eighth of an inch deep, and are beautifully polished.

(d) *Mechanical Wear in Floors, Steps, etc.*: This is an important consideration in stones used for floors and steps. Of the commoner building-stones, granite and quartzite are most resistant. The wearing qualities of sandstones will depend upon the cement between the grains and the strength of the bond it affords. Those having a siliceous cement are most durable, and especially if the cementing silica is united with the grains by crystal growth. Limestones are, as a rule, unsatisfactory floor and step stones, owing to their softness. Some siliceous limestones wear well, and the non-granular varieties outlast the granular.

2. Chemical Agencies: The principal agencies of chemical disintegration are: (1) the normal constituents of the atmosphere—nitrogen, oxygen, carbon dioxide and water vapor; (2) the impurities, or accidental constituents—ammonia; nitric, sulphurous and sulphuric acids; (3) the compounds formed by reactions between members of groups (1) and (2), and the constituents of the stone; (4) organic compounds derived chiefly from plant life.

Of the first group, oxygen, water and carbon dioxide are important. For convenience, their work is frequently referred to under the headings: oxidation, hydration and solution, carbonation. But it is not likely that any one of these processes would be important without one or more of the others, and it may be doubted whether, under natural conditions, any one of these goes on separately. The chemical breakdown of a rock is a very complex process, involving many reactions and interactions. In a paper such as this it is possible to indicate only a few of the more evident changes which take place in the minerals of which building-stones may be composed.

The work of water is manifold. But perhaps it is as a medium through which other chemical reagents may work, that water plays its most important part in the chemical breakdown of rocks. From the air it gathers oxygen, carbon dioxide, sulphuric and nitric acids. From the soil and disintegrating rocks it derives organic acids and mineral salts. All these are carried by it to the rocks with which it comes in contact. But this is, in part, mechanical and in part chemical. Solution and hydration are other important phases of the work of water.

As a solvent, pure water has very little effect upon rock-making minerals. But the waters which come into contact with building stones are rarely pure. They have become dilute acids, and their solvent power is greatly increased.

Limestones and marbles, sandstones with ferruginous and calcareous cement, the feldspars and ferromagnesian minerals of granites and other igneous rocks are most readily attacked. Ordinary pure, compact, non-granular limestones are not so seriously affected. The texture prevents the acidulated waters from penetrating far into the stone before evaporation checks its course. But the porous, crystalline, granular limestones and sandstones offer more favorable conditions for the work of solution. The water penetrates the intergranular spaces, dissolves or weakens the bond between the grains, and prepares the way for crumbling.

Under ordinary conditions, carbon dioxide is probably the most important aid water has in its work of solution. This is due to its universal presence, and to its very general, though slow, solvent action upon the rock-making minerals. In the break-down of the feldspars, the carbon dioxide unites with the potassium, sodium and calcium oxides, forming the corresponding carbonates, which are largely carried away in solution. At the same time, water aluminum oxide and part of the silica unite, forming kaolin. The remaining silica may be separated and deposited as quartz, or it may be dissolved and carried away by the waters holding the alkali carbonates. Feldspars which have undergone such changes are said to be kaolinized. They have lost their luster, hardness, and largely their strength, and are ready to break down into kaolin or clay.

The fracturing resulting from expansion and contraction in response to temperature changes is a great aid in the process of chemical change.

As a rule, the dark minerals—hornblende, biotite and pyroxene—of the granite break-down before the feldspar and quartz. In this process many secondary minerals are formed and may completely fill the space once occupied by the dark minerals. Under certain conditions the new minerals formed require more space than the original, and so mechanical strain results from their formation, but in most cases a part of the constituents will be removed in solution. No matter what the process may be, the result is generally the weakening of the stone.

Hydration, apart from oxidation and solution, is probably of little importance, except where long-continued saturation occurs. So far as building stones are concerned, only those used in foundations are likely to suffer. Even here the mechanical effects of hydration are more important than the chemical.

The oxidation and hydration of the iron-bearing minerals—such as iron carbonate, pyrite and the ferromagnesian minerals of the granites and other crystalline rocks—often result in objectionable discoloration, and occasionally in some disintegration, though it is rarely important. Under certain conditions the new iron minerals formed are deposited as a cement between the grains of the rock.

Sulphuric, sulphurous and nitric acids are present in appreciable amounts only in the atmosphere of large cities, where the consumption of coal is large. Careful tests were made on scrapings from the partially disintegrated surface of the Bedford, Indiana, limestone in the older buildings of the University of Chicago. Traces of sulphur were found in the scrapings from the outer eighth-of-an-inch of the stone. The material analyzed was taken from a building which has stood ten or eleven years, and the results show 2.33 per cent of sulphuric anhydride—an amount almost incredibly large. Assuming that the anhydride is combined with calcium oxide and water in the form of calcium sulphate, 5.01 per cent of the surface material is gypsum. In the change from $CaCO_3$ to $CaSO_4.2H_2O$, 100 parts of $CaCO_3$ will yield 172 parts $CaSO_4.2H_2O$. Making no allowance for loss by solution in the process of change, it is evident that approximately 3 per cent of the surface of the original limestone has been converted into gypsum.

Sixteen analyses of the Bedford stone recorded by Hopkins and Siebenthal[1] show no trace of sulphur.

A microscopic examination showed that considerable intergranular matter had been carried away by solution, but it was impossible to determine satisfactorily the effective agency. It was found that the depth to which this disintegration had gone was by no means proportional to the time of exposure. Comparatively little difference could be observed between the depth of surface weathering in the oldest buildings and that on those one-third the age. It was, however, quite apparent that the mode of dressing the stone and its position in the building were important factors in determining the rate of surface disintegration. The tooth-chiseled surfaces in horizontal position had suffered more than any others. This was no doubt due to the shattering of the surface in dressing, and to the more favorable attitude of the stone for absorbing and retaining moisture. Solution is also aided by organic acids developed in the decay of plant material. Chemically, the formation of soluble salts, such as magnesium and calcium sulphates from the reaction of sulphuric acid on magnesium and calcium carbonates, has but little effect, and the mechanical work has been discussed. The oxidation of iron pyrite may result in the formation of sulphuric acid and cause local chemical action of an injurious character.

III. WORKABILITY

Stones suitable for building purposes differ widely in the ease with which they may be quarried and prepared for architectural use. Under workability must be included quarrying, dressing and decorative working. In quarrying, the larger structural features of the rock mass are of great importance. These include bedding, dip or attitude of the strata, and jointing. It is desirable that the beds should be well defined and of such thickness that all the stone may be marketable without an undue amount of labor. Beds too thin for use must be removed at considerable expense of time and labor, while very thick beds make difficult and expensive quarrying on account of the necessity of splitting the blocks into the desired thickness. The horizontal position of bedding greatly facilitates the handling of the quarry product and makes the use of quarrying machinery more possible. Distinct and regular jointing, in at least one direction, is a boon to the quarryman. In many limestone quar-

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[1] Twenty-first Annual Report, Department of Geol. and Nat. Hist. Indiana, 1896, p. 320.

ries—as, for example, those at Stone City and LeClaire, Iowa—the rock is so distinctly and perfectly laminated that the split surfaces of much of the quarry product need no further dressing.

In igneous rocks, the absence of true bedding-planes makes jointing of even greater importance than in sedimentary rocks, and unless there are rather well-defined joints in an approximately horizontal position, much expensive undercutting or ''gadding'' is necessary.

Dressing is at best a slow and expensive process, and many otherwise desirable stones cannot be placed on the market because of the difficulty of dressing them. Many stones take the chisel with almost equal facility in all directions, while others have such pronounced bedding or grain, or both, that satisfactory working is very difficult. Fine decorative work on such rocks is almost impossible. Again, certain stones readily take a beautiful and lasting polish, while others are difficultly polished and incapable of retaining a good surface. Easy quarrying, easy working and durability make a desirable combination in building-stone.

IV. COLOR

The tone and permanence of color are of considerable importance in building-stones, especially in large cities, where fashion rather than utility may be the determining factor in the choice of building material. It is a rare thing to find absolute uniformity of color in a quarry. Very commonly the color changes with depth and remoteness from exposure to atmospheric conditions, and not infrequently the same bed may show marked differences of color on the two sides of the quarry. The common coloring-matters of sedimentary rocks are carbonaceous material and salts of iron. Carbonaceous matter usually gives brown and black tones, while the iron salts give blues, grays, buffs, browns and reds—the shade depending largely upon the state of oxidation of the iron present. If the iron is present as a sulphide, weathering is likely to cause oxidation and a darkening of the color toward buff, brown and red. If it is in the protoxide form, the color is likely to be gray, blue-gray and blue. Further oxidation may produce about the same tones of buff, red and brown as those from the iron sulphide. A rock colored brown or red by hematite is likely to keep its color, though in time some of the iron may be washed out and leave the stone of a lighter shade.

The irregular distribution of iron compounds, particularly pyrite, may result in unsightly mottling and streaking of the surface of the wall when oxidation and solution take place.

The color of igneous building-stones depends largely upon the important mineral constituents, rather than upon coloring-matter proper. For this reason the color is more likely to be permanent. But if the percentage of the ferromagnesian minerals is large, weathering may result in a complete change of tone or intensity of color, owing to the partial breaking-up of these minerals and the separation of iron salts, and a change in their state of oxidation.

BUILDING STONES IN COLORADO

Colorado is abundantly supplied with excellent granites. They occur mainly in the large pre-Cambrian areas along the great mountain ranges of the state. The quantity is unlimited, and the quality has been proved by laboratory tests, and by actual use to be equal to that of any granites on the market. In the same areas are many large bodies of monzonite, syenite and other coarse-textured igneous rocks equally suited to the purposes of building. A syenite is quarried near Salida, and is placed on the market as "Salida granite." It is a very superior rock for building and monumental use. It is customary to class practically all granitoid igneous rocks used for building purposes as granites.

Among the places at which granite quarries have been opened are: Aberdeen, Arkins, Cotopaxi, Lawson, Lyons, Masonville, O'Neill Spur, Platte Canyon, Silver Plume, Salida, Texas Creek.

Sandstone of excellent quality for building purposes occurs in many geological formations, and in many parts of the state. The principal developments have been along the foothills of the Front Range, simply because these deposits are nearer to the market. But for local use sandstones have been quarried in many parts of the western half of the state.

Operating quarries are located at Arkins, Boulder, Basalt, Beulah, Lyons, Manitou, Morrison, Pueblo, Turkey Creek, Trinidad and many other places.

Lava rock is quarried at Castle Rock, Del Norte, Gunnison, Howard and other places. The rock is admirably suited to many styles of architectural work.

Marble is abundant in Colorado, and is being placed on the market by several companies. The most important developments are those of the Colorado Yule Marble Company, at Marble, Gunnison County.

MISCELLANEOUS USES OF ROCKS

Road Materials: Crushed rock of various kinds, but chiefly granite, limestone, chert, quartzite, and sandstone, is extensively used in road construction and as ballast. It is used both with and without a true bonding material. In general it should have the qualities of toughness, elasticity, and resistance to crushing stress.

The crushed cherty material of the Missouri lead and zinc ores, known as "chats," is much used for road-making.

Paving blocks, sometimes called Belgian blocks, are shaped blocks used for paving where heavy traffic prevails. They are formed of various kinds of stone such as the dolerite (basalt) of Golden and Valmont, certain rhyolites and others.

Disintegrated granite and other rock when not too badly decayed is extensively used for ballast and road building.

Rotten stone is used as a gentle abrasive, and as a polishing powder.

Morrisite is a name given to a pearly white volcanic product, occurring locally in the eastern part of the state. It possesses properties which render it peculiarly fitted for use as a base for pigments of practically all kinds. Tests which have been carried on for several years have given most satisfactory results.

THE MATERIALS OF CEMENTS, LIMES, PLASTERS

Portland Cement "is the product obtained by finely pulverizing clinker produced by burning to semi-fusion an intimate artificial mixture of finely ground calcareous and argillaceous materials, this mixture consisting approximately of three parts lime carbonate (or an equivalent amount of lime) to one part silica, alumina and iron oxide. The ratio of lime (CaO) in the finished cement to the silica, alumina and iron oxide taken together shall be not less than 1.6 to 1, or more than 2.3 to 1."

The Materials used in Portland cement manufacture include: (a) the calcareous material, which may be pure, hard limestone, chalk, argillaceous limestone ("cement rock"), marble or marble refuse, or marl; (b) the argillaceous material, which may be clay, shale or slate; (c) gypsum, which is added mainly to retard the process of setting.

a. *The Calcareous Material*: Absolutely pure limestone is rarely found in large quantities. The common impurities are silica, alumina, magnesia, iron compounds, alkalies and sulphur.

The silica may occur as: chert or flint, fine sand, or associated with alumina in the form of clay, or with other elements in the form of silicates. As a component of clay it is least objectionable, and occasionally a limestone is found which contains silica and alumina in proportions very favorable for cement manufacture.

Alumina is a rare impurity except combined with silica in the form of clay.

Magnesia occurs in the form of the carbonate. There is much difference of opinion regarding the effects of magnesia. As a general rule, it should be kept below 4 per cent.

Iron occurs in the form of oxides, carbonate and sulphide. In the first two of these forms it is not objectionable up to several per cent, as it behaves in much the same way as alumina. In the sulphide form it should never exceed 2 or 3 per cent.

Alkalies: Soda and potash are more likely to be present in the shale than in the limestone. They are considered injurious if the two together exceed 5 per cent of the cement mixture.

A large proportion of the limestones used in Portland cement manufacture carry from 90 to 95 per cent of lime carbonate.

When the mixture of finely ground limestone and clay is burned at sufficiently high temperature, the silica unites with lime (calcium oxide), forming calcium silicates, and the alumina unites with lime, forming calcium aluminates. These new substances have the power of taking up water and crystallizing (''setting'') into a firm cementing or bonding material.

b. *The Argillaceous Material*: The clay should be as free as possible from sand and gravel, and should contain from 60 to 70 per cent of silica. The iron oxide and alumina together should not exceed one-half the percentage of silica. Limy clays (over 5 per cent of CaO) are liable to be irregular in composition, and may cause trouble in securing a mix of the right composition. Clays rich in alkalies or in iron sulphide are avoided.

c. *Gypsum* is used in such small amount that any impurities it may contain are generally negligible.

NATURAL CEMENT: The material used in the manufacture of natural cement varies widely in both physical and chemical character. In general, it is a clayey limestone carrying from 13 to 35 per cent of clayey material, of which about 10 to 22 per cent is silica, while alumina and iron oxide together may vary from 4 to 16 per cent. (Eckel). The hydraulic cementing qualities are due to the chemical reaction between the silica, alumina and iron, on the one side, and the lime, or lime and magnesia, on the other. In this respect natural cement is like Portland. Many limestones used for natural cement are high in magnesia.

ROMAN CEMENT differs but little from the common natural cements, but, as made in Europe, rocks high in magnesia are avoided.

PUZZOLAN CEMENTS, *Slag Cements*: Some volcanic ashes, when finely pulverized, possess hydraulic properties, and, when mixed with lime hydrate (slacked lime), make hydraulic cements of good quality. Blast-furnace slag carrying 30 per cent or more of lime is used extensively in Europe in the manufacture of "Portland" cements. They compare more favorably with natural cements than with Portland cement.

HYDRAULIC LIME is made from limestone containing sufficient siliceous and aluminous matter to give the burnt rock (clinker) hydraulic properties, but not sufficient to prevent it from slacking in much the same manner as ordinary quicklime. The limestones carry from 70 to 80 per cent of lime carbonate and from 13 to 17 per cent of silica. Alumina and iron oxide together may form 3 to 4 per cent.

LIME, *Quick Lime*: When pure limestone is heated to a temperature of 750° to 900° C., the carbon dioxide is driven off and calcium oxide remains. The reaction is represented as follows: $CaCO_3$ (+ heat) $= CaO + CO_2$. Limestones containing magnesium carbonate in varying percentages are also used for making lime. When water is added to quicklime, it slacks, forming lime hydrate, $Ca(OH)_2$, which is the form in which lime is used in masonry, brick-laying and plastering.

Commercially the term "lime" includes *high calcium lime*, containing 90 per cent or over of calcium oxide, CaO; *magnesian lime*, containing from 5 to 25 per cent of magnesia, MgO, and 75 to 95 per cent of calcium oxide; and *high magnesian* to *dolomitic limes*, containing 25 to 45 per cent magnesia and 55 to 75 per cent calcium oxide.

Broadly speaking, the uses of lime may be classed as: (1) building and structural uses; (2) chemical uses. More than one-half the lime produced is used in lime mortars and plasters, Portland cement mortars, concrete and gypsum plasters, and whitewash. The magnesian limes have their principal use in the building trades, but are also used in the chemical industry, while the high calcium limes are used in both building and chemical industries.

The chemical uses of lime are so many that only the more important can be mentioned. These are: in agriculture, as fertilizer, insecticide and fungicide; in the bleaching industry for the manufacture of bleaching powder, and in bleaching paper stock; in the manufacture of soda, potash, ammonia, potassium dichromate, sodium dichromate, magnesia, grain and wood alcohol, bone ash, calcium carbide, rubber, glue, pottery-glazing, glass, soap, glycerine, candles, lubricants, paints and varnishes, linoleum, paper, strawboard; in the refining of fats, greases, butter, petroleum; in purifying illuminating and fuel gases, sugar, molasses, water and sewage; in the metallurgy of iron, mercury and other metals; in tanning, dyeing, etc.

The most important chemical uses are: in agriculture, paper manufacture, chemical works, tanneries, sugar-refining, and glass manufacture.

The lime used in the United States is estimated at 3,500,000 tons annually.

Sand-Lime Bricks: Clean, sharp, fine sand is thoroughly mixed with from 5 to 10 per cent of its weight of lime, molded and pressed into bricks, and allowed to "set" or dry. The process of manufacture varies, but the essential facts are as stated.

Wall Plaster (common) is a mixture of slacked lime and fine sand, to which hair or other binding material is added to make it hold together until it sets. During and after setting a certain amount of carbon dioxide from the atmosphere unites with the lime, forming calcium carbonate. Cement plaster (gypsum plaster) is taking the place of lime plaster for inside work in many localities.

PUTTY COAT or *Hard Finish* is a mixture of plaster of Paris and slacked lime, used for a smooth, hard surface coating on walls and for decorative work.

PLASTER OF PARIS: When gypsum ($CaSO_4.2H_2O$) is heated to a temperature somewhat less than 400° F., three-fourths of the water is driven off, and the material left has the composition $CaSO_4.\frac{1}{2}H_2O$. This is known as plaster of Paris. When moistened with water, it takes up enough water to supply that driven off in the heating, and returns to the gypsum form again. In doing so it "sets," or becomes a firm and hard cementing material.

Uses: Plaster of Paris finds many uses in the building and other trades and arts. The more important are: plaster, moldings and interior decorations of buildings, fireproof wall and wall-filling material, stucco, molds for pottery manufacture and various other purposes, whitewash, floor plaster, Keene's cement, etc.

CEMENT PLASTER is made by adding certain substances known as "retarders" to plaster of Paris. The retarders make the plaster of Paris set more slowly, giving time enough to mix, mold and spread the plaster. Hair is mixed with it to hold it together until it sets. It is much used in place of ordinary lime plaster for interior finish.

FLOORING PLASTERS are made by heating the gypsum to a temperature above 400° F. and driving off all, or nearly all, the water. They must be ground very fine, or they will not set satisfactorily. They set very slowly and form a smooth, hard surface suitable for floors.

HARD-FINISH PLASTERS: These are similar to floor plasters, but their hardness is increased by the addition of alum or borax, or other chemicals, during manufacture.

Stucco is essentially plaster of Paris.

KEENE'S CEMENT, *Parian Cement*: Pure gypsum is calcined at red heat until all the water is driven off. The product is then immersed in a solution of alum, dried, and again burned at high temperature. It is then finely ground.

PLASTER BOARD is made of plaster interlaminated with sheets of cardboard.

CLAYS AND THEIR USES

From the economic or commercial standpoint, clay is fine-grained mineral matter which may be molded and baked into useful forms. It varies in composition from pure kaolin to a complex mixture of kaolin minerals, and the products of rock disintegration and decay.

The kaolin minerals are not easily recognized or distinguished even by chemical tests and analyses. For this reason, only two or three of the more important are described. They are all hydrous silicates of aluminum, differing in the proportions of water, silica and alumina, and in crystal form and molecular arrangement. Some of them are in the form of well-defined but minute crystals, while others are amorphous. For descriptions, see the section on rock-making minerals.

The principal members of the group are:

1. Kaolinite, $2H_2O.Al_2O_3.2SiO_2$.
2. Halloysite, $2H_2O.Al_2O_3.2SiO_2$ + water.
3. Pholerite, $4H_2O.Al_2O_3.3SiO_2$.
4. Rectorite, $H_2O.Al_2O_3.2SiO_2$.
5. Newtonite, $5H_2O.Al_2O_3.2SiO_2$.
6. Allophane, $5H_2O.Al_2O_3.SiO_2$.
7. Indianaite is a residual clay believed by some to be halloysite; by others, allophane.

The mineral and rock grains present in clays include almost every variety of mineral and many kinds of rock. The commonest minerals are quartz (in the form of sand), feldspar, mica, iron oxides, pyrite, siderite, calcite and gypsum; but hornblende, pyroxene, garnet, zircon and many others are found in common clays.

ORIGIN: Clay is a product of the decay of rocks. Primarily it comes mainly from the igneous rocks, particularly those rich in feldspar, but secondarily also from sedimentary rocks. The agencies of decay are: (a) mechanical, (b) chemical. The purely mechanical changes would yield unaltered mineral and rock grains. The chemical changes cause both the breaking-up of existing minerals and the formation of new minerals. The processes of rock decay and the formation of clay have been discussed under weathering (p. 315).

CLASSIFICATION: The geologist groups clays as: (1) residual, (2) transported. To the first group belong those clays which have not been removed from the place of origin. To the second belong those which have been carried by water, wind or ice, and deposited as sediments at a distance from their place of origin.

Marine Clays are those which were deposited on the sea-floor. The older marine clays have been consolidated into shales, and many of them have been raised above sea-level.

Lake (or Lacustrine) Clays are those which were distributed over the floors of lakes and ponds.

Glacial Clays, Drift, Boulder Clay, Till are names applied to clays which are in part the product of the grinding of rocks by glacial ice, and in part the residual clay or mantle rock of the areas over which the ice passed.

River Clays are those deposited along river courses in flood plains, bars and deltas.

Æolian Clay, Loess: When finely divided, dry clays are exposed to the action of strong winds, large quantities are caught up as clouds of dust and swept along, and deposited in sheltered places, where the carrying power of the wind is decreased. Flood plains, deltas, bars, dry lake-beds and areas of residual rock furnish the material for this work of the wind. Deposits of this character cover large areas in the Mississippi basin and in places reach a depth of 100 feet or more. In eastern and western Colorado considerable areas of wind-deposited clay exist, but the beds are not thick.

The uses to which clays may be put depend upon their physical properties and chemical composition. The most important physical properties are: *plasticity, fusibility, tensile strength* and *shrinkage.*

Plasticity is that property through which certain clays, when moistened, may be molded and dried without crumbling or change of form. Plasticity is not well understood, but seems to be dependent upon the texture, the presence of colloids, the behavior of the grains toward water, and the presence of combined water.

Fusibility: The temperature at which clays become viscous depends mainly upon their composition. Ferric oxide (Fe_2O_3), lime (CaO), magnesia (MgO), potash (K_2O) and soda (Na_2O) are known as fluxing impurities, and, when present in any considerable amount, render the clay fusible at low temperature. Clays having little or none of these impurities are generally fusible only at high temperatures, and are known as refractory clays. In fusing, three stages are recognized: (a) incipient fusion—the grains soften and stick together; (b) vitrification—the grains run together and close up all pores; (c) viscosity—the mass swells, softens and becomes viscous, or may even flow.

Tensile strength is the tenacity with which the particles hold together. It is measured by the pull-strain which is required to rupture an air-dried sample of given form and size.

Shrinkage: (1) Air shrinkage: When clay is moistened for molding, thin films of water separate the particles and the volume is increased. In air-drying, the added water is evaporated, the particles come together again, and the volume of the clay decreases. (2) Fire shrinkage: The air-dried clay is porous from the loss of the added water, and it still contains combined water. As the clay is heated, the combined water is driven off, the particles of clay mass together, fill the pores, and the volume decreases. By mixing clays having different shrinkage ratios, a satisfactory shrinkage can be secured.

CHEMICAL COMPOSITION: From what has been said of the origin and mineral composition, it is evident that the chemical composition is remarkably variable. Kaolin has the composition: SiO_2 46.3 per cent, Al_2O_3 39.8 per cent, water 13.9 per cent, and high-grade clays should show these constituents in about the same proportion.

Silica occurs as quartz sand, as a constituent of kaolin, and in the silicate mineral grains, such as feldspar, mica, garnet, etc. The following table (from Ries) shows the range and the average silica content of several hundred clays by varieties.

	Range of per cent	Average per cent
Brick clays	34.35 to 90.87	59.27
Pottery clays	45.06 to 86.98	45.83
Fire clays	34.40 to 96.79	54.30
Kaolins	32.44 to 81.18	55.44

In the form of sand it decreases the air shrinkage, the plasticity and the tensile strength. It raises the fusion point of clays rich in fluxing impurities and silica, but lowers the fusion point of clays high in alumina and low in fluxes.

Alumina is highly refractory, and is very constant in its behavior.

Iron is commonly present in the oxide form, but may occur as a carbonate, or in iron-bearing silicates, such as biotite and hornblende. It is the most important coloring agent, and gives the brick or other product shades varying from buff to deep red. The depth of color depends upon the amount of iron present, the form in which it occurs, the mode of burning the clay, the modifying effects of lime, carbonaceous matter, etc. Iron oxide lowers the fusion temperature of clay, and is therefore an objectionable impurity in fire-clay.

Lime may be present in the carbonate form as calcite, or as grains of limestone or dolomite; in the sulphate form as gypsum; or in the lime-bearing silicates, such as plagioclase. It acts as a fluxing agent, causing the clay to soften quickly in the kiln. If present in large grains or pebbles, it forms quicklime, which slacks and breaks the brick. Gypsum seems to be a rather objectionable impurity. The sulphur is not all driven off in brick-burning, and that which remains behind appears to unite with the lime and alumina, forming the sulphates of lime and alumina. These appear as a white crystalline powder coating the brick, and by their crystallization cause disintegration. If the burning of the brick is carried to vitrification, the sulphur is either driven off, or chemical changes are brought about which prevent the formation of these injurious soluble salts. Contrary to the general opinion, good brick and other clay ware may be made from clays having a high lime content, providing it is in a very finely divided condition. The following table (from Ries) shows the range and average lime content in several varieties of clay, as shown by analyses:

	Range of per cent	Average per cent
Brick clays	0.024 to 15.38	1.513
Pottery clays	0.011 to 9.90	1.098
Fire clays	0.03 to 15.27	0.655
Kaolins	Trace to 2.58	0.47

Some Milwaukee brick clays contain over 20 per cent of lime, and the London malms or stock bricks often contain over 40 per cent of lime.

Magnesia acts as a flux, and makes the clay soften slowly when burning.

The *Alkalies*: *Soda* and *Potash,* are derived mainly from the feldspars and micas, but glauconite, hornblende and other minerals may add a little. They are the strongest fluxing material contained in clays, and serve to bind the baking clay into a dense, hard body at comparatively low temperature. They are very detrimental in fire clays. Feldspar, the principal source of potash, is used as a flux in the manufacture of porcelain, white earthenware, and other products made from white-burning clays.

KINDS AND USES OF CLAYS

China Clay, Kaolin, Rock Kaolin, Indianaite, are non-plastic residual clays in which kaolinite and silica are the principal constituents. They are low in the fluxing impurities, and are consequently refractory. They are seldom naturally fit for use, but must be washed and mixed with other materials, especially feldspar. They are used for the manufacture of whiteware, porcelain, tiles, insulators in electrical engineering, and for sizing and weighting paper.

Ball Clay, Ware Clay, is a white-burning plastic clay used mainly in the pottery industry for giving strength and plasticity to the non-plastic clays used in whiteware manufacture.

Fire Clays: Practically any residual or sedimentary clay possessing high refractoriness may be used as a fire clay. Plastic and non-plastic fire clays may occur in the same bed. Much of the sedimentary fire clay of this country comes from beneath the coal seams. An excellent fire clay comes from the Dakota formation of Colorado, and is not associated with coal. The principal uses of fire clay are for the manufacture of: fire bricks, furnace linings, retorts, crucibles, tiles, terra-cotta, paving-bricks, pressed bricks, etc.

Brick Clays: These are impure plastic clays having, as a rule, a fairly high percentage of fluxing impurities, which cause them to burn to a hard product at low temperatures. Most brick clays contain sufficient iron to give a brick a red color.

Paving-Brick and Sewer-Pipe Clays are generally fairly high in fluxing impurities, have fair plasticity, and vitrify at medium temperature. Some fire clay is generally added for sewer pipe to make it stand up better in the kiln.

Terra-Cotta Clays: Low-grade fire clays and mixtures of these with common brick clays are mostly used.

Stoneware Clay: A refractory or semi-refractory vitrifying clay of sufficient tensile strength and plasticity to be workable on a potter's wheel. These qualities are commonly secured by mixing clays of different properties.

Slip Clay is used for glazing various types of pottery. It is mixed to a creamy consistency and sprayed over the pottery, or the pottery is dipped into it. It is a very fine-textured, easily fusible clay.

Fireproofing and Hollow-Brick Clay should have rather high plasticity, fair tensile strength, and should "burn to a good hard, but not vitrified body at a comparatively low temperature." These requirements leave a rather wide range of choice of raw material.

Gumbo or Ballast Clays are fine-grained, dense, plastic clays of rather high tensile strength. They have been burned in unmolded form for ballast, but their use seems to be declining.

Paper Clay: Washed kaolin and certain fine-textured, fairly plastic sedimentary clays free from sand are used to give body, weight and firmness to various kinds of paper.

Portland Cement Clays: These are discussed under cement materials.

Paint Clays: Certain highly ferruginous or ocherous clays and shales are finely ground, mixed with oil, and used as mineral paints.

Adobe is used for making sun-dried bricks.

Fuller's Earth is a clay having high absorption powers for certain substances, and consequently the power to remove these substances from liquids containing them. It is so variable in color, composition and general appearance that the only certain means of identifying it is a test of its power of absorption. A few facts may, however, be of use in a search for fuller's earth. The commonest colors are greenish-white, greenish-gray, olive and brownish. It is soft, friable and greasy to the touch. It is non-plastic, and when a piece is placed in water it crumbles down to a fine, easily disturbed mass, giving a slight milkiness to the water. Chemical analyses show that it contains more combined water than most clays.

Uses: The principal use of fuller's earth is in deodorizing, bleaching, clarifying or filtering fats, greases, vegetable, animal and mineral oils. It is extensively used in the refining of petroleum. A small amount is still used in the woolen industry for removing the natural oils from yarn and cloth. The average price for 1914 was $9.85 per ton.

SUMMARY OF CLAY PRODUCTS

1. *Pottery*: Porcelain ware, chinaware, granite or ironstone ware, yellow ware and earthenware.

2. *Structural and Ornamental*: Brick—pressed, common, ornamental, hollow, glazed, paving; tile—flooring, roofing, wall and ornamental, drain, fireplace; chimney flues, chimney pots, door knobs; terra cotta—moldings and decorations; railway ballast.

3. *Agricultural*: Tile—drain, irrigating and soil; tempering soils.

4. *Hydraulic and Sanitary Engineering*: Water conduits, reservoir linings, sewer pipe, water closets, basins, absorbent brick, drain tiles, ventilating flues.

5. *Industrial Arts*: Crucibles, retorts, furnace linings, puddling hearths, smelting furnaces, stove linings, glass pots, insulating materials in electrical engineering, filling for walls, sizing and filling for paper; cement manufacture, mineral paint and paint adulterants.

I. MATERIALS CLASSIFIED BY USES

ABRASIVES

Abrasives are materials used for grinding, smoothing, and polishing metals, stone, minerals, jewels, wood and various artificial substances.

The qualities desired in an abrasive for grinding are: a hardness greater than that of the material to be ground, sharp cutting edges or points, the absence of flat or tabular grains, a tendency to break under wear and form new cutting points, and uniformity of texture, hardness and general shape.

For polishing the material must be very fine, uniform and, as a rule, softer than the substance to be polished.

The following substances used as abrasives are described elsewhere:

Alundum,
Axolite,
Bort, boort,
Carbonado,
Corubin,
Corundum,
Diamond,
Diatomaceous earth,
Emery,
Feldspar,
Flint pebbles,
Fuller's earth,
Garnet,
Grindstones,
Millstones,
Novaculite (Arkansas stone),
Oilstones,
Pulpstones,
Pumice,
Putty powder,
Quartz,
Rotten stone,
Rouge,
Sandstone,
Steel (crushed),
Tripoli,
Volcanic ash,
Whetstones,
Zinc white,
Zircon.

CHEMICAL MATERIALS

Almost every element described yields some material used in the chemical industry. A few of the more important are mentioned in discussing the uses of the element and its compounds.

FERTILIZERS

These are substances used for three main purposes: *a* to enrich the soil and furnish plant food directly; or *b* to react with the substances of the soil and form plant food, and *c* to render the contents of the soil available to the plant by making them more soluble.

The more important mineral fertilizers are listed below.

Ammonium salts, particularly the sulphate:
Calcium compounds:
    Apatite, calcium phosphate, is converted into superphosphates,
    Calcium nitrate,
    Gypsum, calcium sulphate, ground, called land plaster,
    Lime, calcium oxide,
    Marl and chalk, both raw and calcined,
    Phosphate rock, calcium phosphate, is converted into superphosphates;
Greensand, glauconitic sand;
Guano, a phosphatic material;
Potassium salts of various kinds;
Slag from the basic processes of steel-making;
Sludge products from petroleum refining;
Sodium nitrate, Chili saltpeter;
Superphosphates, made from apatite and phosphate rock.

FILTERING MATERIALS

These are materials used for clarifying liquids of various kinds. The commoner mineral filtering substances are listed below. They are described elsewhere.

Coal slack and coke,
Diatomaceous earth,
Fuller's earth,
Glass fiber or wool,
Infusorial earth,

Pumice, both in blocks and in the form of powder and volcanic ash,
Sand,
Tripoli,
Quartz, crushed.

FLUXES

Fluxes are used to aid in the process of fusion, to cleanse surfaces for welding, soldering, and brazing, and for the production of a liquid slag which will gather and float off the impurities of ores, metals, alloys, etc. The commoner fluxes are:

Fluorspar, fluorite,
Garnet,
Iron ores,
Limestone,
Manganiferous iron ores,
Quartz, silica.

In the metallurgy of steel various alloys are used to cleanse the steel from impurities by reacting with them and carrying them to the top as slag. These include: aluminum powder, ferromanganese, ferrotitanium, ferrosilicon and other alloys.

FUELS AND ILLUMINANTS

These are discussed in a section by themselves. They include:

A. Gaseous:
  Air gas,
  Coal gas,
  Natural gas,
  Producer gas,
  Water gas.

B. Liquid:
  Petroleum, crude, and its products.

C. Solid:
  Coals,
  Coke,
  Lignite,
  Peat.

GEM MINERALS AND SEMI-PRECIOUS STONES are listed and described elsewhere.

GLASS, PORCELAIN AND POTTERY MATERIALS

A. Glass materials:

Silica in the form of crushed quartz, quartz sand or crushed sandstone is the most important constituent;
Sodium sulphate (salt cake);

Lime in the form of calcite, limestone, marble or chalk;
Potassium nitrate and occasionally other potassium salts;
Lead in the form of red lead, white lead and litharge;
Cryolite;
Fluorite.

Special kinds of glass are made by using the oxides of antimony, arsenic, aluminum, barium, iron, magnesium, manganese, zinc, etc., instead of potash, soda, lime and lead.

The coloring materials are mainly oxides of the metals.

B. Porcelain and Pottery Materials:

Kaolin and kaolinite,
Feldspar,
Silica,
Pottery clays,
Slip clay.

The materials of glazes used in pottery manufacture include clays of various kinds, feldspar, oxide of lead, lime, silica, salt, diatomaceous earth, etc.

INSULATING MATERIALS

Many mineral substances, both raw and manufactured, are used in architectural, civil, mechanical and electrical engineering, as obstacles to the passage of heat, sound and electricity, and as a means of saving heat, etc. The more important of these may be grouped as follows:

A. Heat Insulation:

Asbestos, and mixtures of asbestos with various other materials such as: clay, sand, magnesium carbonate both calcined and raw, plaster of Paris, powdered limestone, sawdust, paper, hair, etc.

Diatomaceous earth,
Infusorial earth,
Magnesia (calcined magnesite),
Mineral wool, etc.

B. Soundproofing materials:

Asbestos and asbestos compounds,
Mineral wool,
Stucco,
Diatomaceous earth.

C. Electrical insulation:

Asphalt and bitumen,
Glass and porcelain,
Marble,
Mica, micanite,
Slate.

LUBRICANTS

The following mineral substances are used in the manufacture of lubricants:

Graphite,
Mica,
Oils from petroleum,
Talc and soapstone.

PAPER-MAKING MATERIALS

In the manufacture of paper of various kinds a number of mineral substances are used. Some of them are employed in chemical processes and others in weighting and sizing the papers.

The more important chemical materials are the sulphites of calcium, magnesium and sodium, lime and chloride of lime, and sulphurous acid obtained commonly from pyrite.

The weighting materials are barite, magnesite, clay free from sand, bauxite, etc.

PIGMENTS AND PAINT MATERIALS

A great many mineral substances are used in the paint industry. Some of these are prepared from the raw materials by mechanical processes such as grinding, and floating, while others are prepared by chemical processes. To the first group belong such substances as barite, graphite, gypsum, ochres, china clay, slate, natural ultramarine and others. To the second group belong the arsenic, cadmium, copper, cobalt, lead, mercury and zinc pigments. The following list includes a number of the more important sources of mineral paint materials. In many cases fuller discussions will be found by referring to the metal or other substance in the main text of the bulletin.

Compounds of the following metals are used in the paint industry:

Arsenic, (green, yellow and orange),
Antimony, (yellow, orange and vermilion),
Aluminum, (in the preparation of lakes, etc.),
Barium, (blanc fixe, permanent white, lithophone),

Cadmium, (yellow),
Chromium, (green, red, orange, yellow, violet),
Cobalt, (blue, green, ultramarine),
Copper, (greens chiefly),
Iron, (umbers, siennas, ochres, red, orange, scarlet, etc.),
Lead, (white, yellow, red, orange, scarlet, etc.),
Mercury, (vermilion),
Zinc, (white mainly).

Among the non-metallic substances used are:

Asphalts and bitumens, (rust-proof coverings),
Barite, (See barium above),
China clay, (chiefly in making lake pigments),
Graphite, (weather-proof surfacings),
Gypsum, (as body in many pigments especially those using water as a means of suspending the powder),
Hydrocarbons, solid and semi-solid, coal tar, etc., (weather-proof coverings),
Kaolin, (See china clay),
Lamp black, (blacks, grays, etc.),
Morrisite, (a white volcanic product used as a base for pigments),
Silica, powdered, (many outdoor paints),
Slate, powdered, (outdoor use mainly),
Ultramarine, (blue and green),
Whiting, (whites, gray, etc., mainly in water-mixed tintings).

REFRACTORY MATERIALS

These are used for furnace linings, crucibles, chemical vessels, fireproofing, and in other places where high temperatures must be resisted. They are discussed under the following headings:

Alundum,
Asbestos,
Bauxite,
Chromite,
Dolomite,
Fire clay,
Fire sand,
Graphite,
Magnesite,
Quartz,
Silica and silica sand,
Talc, etc.

SALINES

The various minerals commonly classed as salines are discussed under boron, calcium, magnesium, potassium and sodium.

STEEL-HARDENING AND STEEL-CLEANSING MATERIALS

These are discussed under:

Aluminum,
Carborundum,
Chromium,
Manganese,
Molybdenum,
Nickel,
Silicon,
Titanium,
Tungsten,
Uranium,
Vanadium.

STRUCTURAL MATERIALS

Geological products furnish a great variety of building materials used in all branches of engineering and architecture. They are discussed under building stones, clays, cements, limes, etc. The more important may be grouped as:

1. Building stones:
    - Granites (including other igneous rocks),
    - Limestones,
    - Marbles, and serpentine rock,
    - Sandstones,
    - Slate.
2. Cements, Limes and Plasters:
    - Portland cement,
    - Rock cement, natural rock cement, Roman cement,
    - Puzzolan and slag cements,
    - Lime, quicklime, and lime hydrate,
    - Hydraulic lime, water lime,
    - Gypsum products, including:
        - Gypsum plaster, cement plaster,
        - Plaster of Paris,
        - Stucco,
        - Floor plasters and hard cement plasters;
    - Filling materials for cements and mortars:
        - Sand, gravel, crushed stone, etc.;
    - Roofing asphalt, tar, cement, etc.
3. Clay Products:
    - Bricks for building, paving, etc.;
    - Firebricks,
    - Hollow clay materials, sometimes called clay lumber, etc.;
    - Terra cotta,

Tiling for roofing, flooring, etc.;
Sanitary ware,
Sewer pipe, conduits and drain tile.

4. Road Materials:

Flagging stones,
Paving blocks,
Crushed stone,
Disintegrated rock, residual gravel, rotten rock,
Gravel,
Sand,
Asphalt, bitumen, coal tar.
Cements.

GLOSSARY

Acicular crystals. Needle-like crystals.

Adamantine luster. The luster of the diamond.

Alkalies. The important alkalies are sodium and potassium. The alkaline earths are calcium, magnesium, barium and strontium.

Alkaline. Having the behavior or taste of an alkali. Soda has an alkaline taste.

Amorphous. Without crystal form or structure.

Amygdaloidal. Having almond-shaped or sub-globular masses of mineral filling bubble-holes or similar openings. Many basalts are amygdaloidal.

Anhedral. Without crystal faces or boundaries.

Arborescent. Tree-like.

Asterism. A star-like arrangement of the rays of light passing through certain minerals, as phlogopite.

Astringent. A taste which puckers the mouth.

Bismuth flux. A mixture of one part potassium iodide, one part acid potassium sulphate and two parts of flowers of sulphur.

Bladed structure. Consisting of parts resembling knife blades.

Blebby. Bubbly.

Botryoidal. Resembling the surface of a compact bunch of grapes.

Capillary. Hair-like.

Chatoyant. A luster resembling the changing luster of the eye of the cat at night.

Clastic. Composed of fragments of minerals or rocks.

Columnar. Composed of pencil-like bars in more or less parallel arrangement.

Conchoidal fracture. A fracture having a curved surface resembling the surface of a shell.

Crypto-crystalline. Composed of crystals or crystal grains so minute as to be indistinguishable to the unaided eye.

Decrepitate. To fly to pieces.

Dendrites. Fern-like forms resulting from the crystallization of oxide of manganese and possibly oxides of iron in seams.

Dendritic structure. A structure made up of branching fern-like parts.

Drusy. Covered with minute crystals.

Ductile. That may be drawn into wire.

Earthy fracture. A fracture resembling that of a lump of hard clay.

Effervescence. The rapid bubbling due to the escape of gas.

Efflorescence. The property possessed by some crystals of breaking down into grains or powder.

Elastic. When a plate of fresh muscovite is bent and then released, it will immediately straighten out. Such a mineral is elastic.

Exfoliate. To swell up and open into leaves or plates like a partly opened book.

Ferromagnesian. Containing iron and magnesium. The important ferromagnesian minerals are the pyroxenes, the amphiboles, biotite and olivine.

Fibrous. Composed of fibers.

Filiform. Thread-like or hair-like.

Flame coloration. The color imparted to the blowpipe flame by the volatilization of certain elements, chiefly metals.

Fluorescence. The giving out of light while the temperature is below the usual light-giving range. Fluorspar, when moderately heated, glows brightly.

Foliated. Composed of leaf-like plates.

Fusibility scale. For convenience of description the fusibilities of certain minerals are taken as a scale of reference. The minerals are: 1, Stibnite; 2, Natrolite; 3, Almandite garnet; 4, Actinolite; 5, Orthoclase; 6, Bronzite.

Globular. Composed of rounded masses.

Hackly. Rough and ragged like the fracture surface of steel.

Idiomorphic. Possessing its own natural crystal outline.

Intergrowth. The interlocking of crystals due to their crystallizing at the same time and in contact with one another.

Intumescence. The swelling and sputtering due to the escape of water during heating.

Iridescence. The appearance of peacock colors on the surface of, or within, certain minerals.

Lamellar. Composed of thin parallel plates.

Laminae. Thin plates.

Lenticular. Lens-shaped.

Magma. A mass of molten rock within the earth.

Malleable. That may be hammered out into plates.

Mammillary. Consisting of low rounded masses.

Massive. Without definite structural features.

Meteorites. Masses of mineral or rock matter coming to the earth from space. Shooting or falling stars are meteorites which have become heated by contact with the atmosphere.

Native elements. Elements occurring uncombined with others.

Non-metallic. Minerals in which the metallic elements (metals) are not prominent are said to be non-metallic.

Oolitic. Consisting of small rounded grains resembling fish eggs.

Opalescence. The peculiar luster and translucence of the opal.

Opaque. Not permitting the passage of light.

O. F.

Oxidizing flame. The outer cone of the blowpipe flame.

Pearly luster. The peculiar glimmering luster characteristic of the inner surface of a fresh oyster shell.

Percussion figure. A figure consisting of radiating lines formed in such minerals as mica and chlorite by a blow with the point of a somewhat sharp instrument.

Phenocryst. A large or prominently showing crystal in a finer grained ground mass.

Pisolitic. Consisting of rounded grains like peas or beans.

Porphyritic. Containing phenocrysts or large crystals in a fine ground mass.

Pseudomorph. A crystal taking the form of the crystal of another mineral.

R. A general symbol used for metallic elements where any one of two or more may occur.

Radiated. Diverging like the spokes from the hub of a wheel.

Reaction. The action of one chemical substance upon another accompanied by the formation of a new substance.

R. F.

Reducing flame. The inner blue cone of the blowpipe flame. It removes oxygen.

Reduction. The action of removing oxygen.

Sectile. That may be cut without crumbling, as a piece of metallic lead or a piece of wax or horn.

Stalactite. A mineral in the form of an icicle.

Striations. Very fine parallel lines marking the surfaces or cleavage faces of minerals.

Strike figure. See percussion figure.

Sublimate. A coating or deposit formed in a glass tube or on charcoal as a result of heating certain minerals.

Subvitreous. A luster less glassy in appearance than that of common glass.

Tarnish. A change of color resulting from exposure to atmospheric action.

Test paper. A chemically prepared paper which changes color when brought into contact with certain substances, particularly acids and alkalies.

Turmeric paper. A test paper colored yellow by turmeric, and used for detecting borates, etc.

Vitreous luster. The luster of broken glass. The glassy luster.

INDEX

Page
Abrasives 437
Absarokite 366
Acanthite 230
Acicular crystals 445
Acmite 44
Actinolite 46
Actinolite schist 404
Adamantine luster 28, 445
Adamellite 333, 335
Adobe 380, 436
Adularia 36
Aegirite 44
Aegirite trachyte 352
Agate 153
  moss 153
Agatized wood 153
Aguilarite 147
Aikinite 211, 247
Ailsyte 328
Alabandite 172
Alabaster 79
Alaskaite 236
Alaskite 326
Alaskite porphyry 328
Albertite 113, 115, 387
Albite 34, 35, 36
  crystal form 24
Alexandrite 150
Algodonite 208
Alkali 142
Alkalies 445
Alkaline 445
Allanite 253
Allemontite 241
Allophane 79, 431
Alloys (see under various metals)
Almandine 65
Almandite 65
Alnoite 359
Altaite 213, 218
Alum 82, 222
  Colorado localities 83
  native 134
  natural 82
Alum clay 82, 83
Alum, potash 134
Alum shale 82, 83, 382
Alum slate 82, 83
Aluminite 84
Alumino-ferric cake 223
Aluminum and aluminum minerals 222, 225
  alloys of 222
  non-metallic minerals 81
  ores 223
  tests for 258
  uses 222
Aluminum bronze 198
Aluminum sulphate 222
Alumstone 134
Alundum 223, 437
Alunite 134
Alunogen 83
Amalgam 234, 249, 251
Amazonstone 149
Amber 119
  uses 120
Amber mica 32
Amblygonite 124
Ambrite 120
Amethyst 153
  oriental 152

Page
Amethystine 153
Ammonia 129
Ammonium molybdate 173
Ammonium salts 438
Ammonium sulphate 104
Amorphous 445
Amorphous limestone 384
Amphibole, alteration of 317
  crystal form 23
  group 45
Amphiboles and pyroxenes 40
  economic uses 77
Amphibolite 404
Amygdaloidal structure 312, 445
Analcite 59
Anatase 182
Andalusite 66
Andesine 35, 37
Andesite breccias 345
Andesite group 343
Andesite, hornblende 343
Andesite-obsidian 328, 345
Andesite-perlite 345
Andesite-pitchstone 345
Andesite-porphyry 343
Andesite-pumice 345
Andesite, pyroxene 343
Andesite tuffs 345
Andradite 65
Anesthetics from coal tar 105
Anglesite 209
Anhedral 445
Anhydrite 73, 93
Aniline salts 105
Ankerite 74
Annabergite 178, 242
Anorthite 34, 35, 37, 93
Anorthoclase 34, 36
Anorthosite 364
Antimony and antimony minerals 242, 244
  gray 243
  native 242
  ores 242
  tests 258
  uses 242
Antimony glance 243
Antimonite 243
Antiseptic, coal tar product 105
Anthophyllite 77
Anthracite coal 100, 387
Anthraxolite 115
Apatite 93, 130, 438
  crystal form 19
Aphanites 305
Aphanitic texture 292, 306
Aphthitalite 135
Apjohnite 82
Aplite (granitic) 326
Aplome 65
Apophyllite 62
Aporhyolite 327
Aquamarine 149
Aragonite 73, 93
Arborescent 445
Architectural marbles 409
Ardennite 198
Arenaceous limestone 386
Arenaceous rocks 372
Arfvedsonite 47
Argentite 230
Argentiferous galena 230

Page
Argentiferous tennantite ... 233
Argentiferous tetrahedrite ... 233
Argillaceous limestone ... 386
Argillaceous rocks ... 378
Argillaceous sandstone ... 377
Argillite or slate, Phyllite ... 398
Argyrodite ... 236
Arkansas stone ... 393, 437
Arkose ... 377
Arsenic and arsenic minerals ... 239
  native ... 240
  tests for ... 259
  uses ... 239
Arsenic sulphide ... 239
Arsenical pyrites ... 164
Arsenolite ... 242
Arsenopyrite ... 164, 242
Asbestos, asbestus ... 77, 440
Asbolite ... 173, 181
Asphalt ... 114, 387
Asphalt and bitumen ... 440
Asphalt rock ... 118
  Colorado localities ... 118
  uses ... 119
Asphaltum ... 114
Asteriated quartz ... 154
Asterism ... 445
Astringent ... 445
Atacamite ... 206
Atom ... 10
Atomic weights ... 258
Augen gneiss ... 398
Augite ... 44
Augite andesite ... 343
Augite diorite ... 341
Augite lamprophyre ... 354
Augite minette ... 353
Augite rock ... 408
Augite syenite ... 350
Augite trachyte ... 352
Augitite ... 367, 370, 372
Aurichalcite ... 206
Autunite ... 195
Aventurine quartz ... 153
Awaruite ... 162
Axinite ... 51
  crystal form ... 24
Axolite ... 437
Azurite ... 202

Ball clay ... 434
Ballast clay ... 435
Banakite ... 353
Barite ... 85
  Colorado localities ... 86
  crystal form ... 21
Barium and barium minerals ... 84
  tests for ... 259
  uses ... 84
Barium salts ... 84, 85
Barytes ... 85
Barytocalcite ... 86
Barytocelestite ... 144
Basalt ... 306, 340, 350, 364, 366
Basalt porphyry ... 306, 366, 367, 370
Basaltic breccias ... 367
Basaltic tuffs ... 367
Basanite ... 359
Bastnasite ... 257
Batholiths ... 292
Bauxite, beauxite ... 223
Beegerite ... 247
Bell-metal ... 198, 220
Bell-metal ore ... 221
Bentonite ... 80
Benzene ... 105
Beryl ... 88, 149
Beryllium ... 88, 252, 259
  uses ... 88
Berzelianite ... 148
Beta-spodumene ... 123
Binary granite ... 323
Biotite ... 30, 31, 76

Page
Biotite gabbro ... 364
Biotite gneiss ... 396
Biotite granite ... 323
Biotite-hornblende dacite ... 336
Biotite-muscovite granite ... 323
Biotite schist ... 402
Biotite-sillimanite schist ... 402
Biotite trachyte ... 352
Birds-eye marble ... 410
Bismite ... 246
Bismuth alloys ... 245
Bismuth and bismuth minerals ... 245
Bismuth chromate ... 245
Bismuth flux ... 445
Bismuth glance ... 245
Bismuth, native ... 245
  tests for ... 259
  uses ... 245
Bismuth ochre ... 246
Bismuth oxychloride ... 245
Bismuthinite ... 245
Bismutite ... 246
Bitumen ... 114
Bituminous coal ... 99, 102, 387
Bituminous limestone ... 384
Bituminous rock ... 118
Bituminous shale ... 110, 382
Bixbyite ... 173
Black diamond ... 94
Black garnet ... 65
Black hematite ... 170
Black-Jack ... 216
Black lead ... 93
Black lignite ... 387
Black mica ... 31
Black sands ... 375
Bladed structure ... 437, 445
Blanc fixe ... 441
Bleaching powder ... 92
Blebby ... 445
Blende ... 216
Blodite ... 129
Bloodstone ... 153
Blue iron earth ... 165
Blue vitriol ... 207
Boghead cannel ... 118
Bornite ... 201
Boracic acid ... 88
Boracite ... 89
Borax ... 88, 137
Boron and boron-bearing minerals ... 88, 91
  tests for ... 260
Boronatrocalcite ... 90
Bort ... 94, 437
Bosses and stocks ... 298
Botryoidal ... 445
Boulder clay ... 380
Boulders ... 377
Bournonite ... 214, 244
Brachy-axis ... 23
Brachy-pinacoid ... 22
Brass ... 198
Braunite ... 171
Brazilian pebbles ... 154
Breccia ... 378
  basalt ... 307
  dacite ... 336
  felsite ... 307
  rhyolite ... 323
  and tuff ... 307
Breccia marble ... 410
Breithauptite ... 181
Brick clay ... 381, 435
Bristol diamonds ... 154
Britannia metal ... 220, 242
British Thermal Unit (B. T. U.) .. 97
Brittle micas ... 30, 53
Brittle silver ore ... 232
Brochantite ... 204
Broggerite ... 191

Page
Bromine, and sources of 91, 92
  uses 91
Bromyrite 92, 235
Bronze 221
  aluminum 198
  phosphor 198
  staturay 198
Bronzite 41
Brookite 182
Brown coal 99
Brown spar 74
Brucite 128
Buhrstone 405
Building materials in general ...411
Building sand 375
Building stones 411, 440, 443
  cementation 414
  chemical aggregations 414
  chemical agencies, effect of....420
  color 424
  Colorado 425
  composition 413
  crystal aggregates 414
  dressing 424
  durability 415
  essential qualities of 412
  mechanical agencies 415
  mechanical wear 420
  mode of aggregation 414
  organic acids, effect of 422
  quarrying 423
  strength 412
  stresses 414
  structure 413
  temperature changes, effect of..415
  tensile strength 415
  texture 413
  transverse stress 415
  water, effect of 418, 421
  weathering 421
  wind, effect of 420
  workability 423
Burmite 120
Bytownite 35

Cadmium, and sources of........251
Cadmium alloys 251
  uses 251
Cadmium-blende 251
Cadmium cell 251
Cadmium spectrum 251
Cairngorm stone 154
Calamine 217
Calaverite 228, 236, 248
Calcareous rocks 382
Calcareous sand 375
Calcareous shale 381
Calcareous sinter 392
Calcareous tufa 392
Calciocelestite 144
Calciovolborthite 197
Calcite 71, 78, 93
  crystal form 19
  uses 78
Calcium and calcium minerals..92, 93
  tests for 260
Calcium borate 390
Calcium carbide 92
Calcium compounds 92, 438
  sources 92
Calcium tungstate 185
Calc spar 71
Californite 150
Calomel 250
Calorific intensity 98
Calorific power 98
Calorie 98
Camptonite 343
Cancrinite 39
Canfieldite 236
Cannel coal 106
Caoutchouc, mineral 116
Capillary 445

Page
Capillary pyrites 176
Carbolic acid 105
Carbon 261
  tests for 261
Carbon and hydrocarbon series of minerals and rocks...... 93
Carbonaceous rocks 387
Carbonaceous shale 382
Carbonado 94, 437
Carbonite 100, 116, 387
Carborundum 75
Carnallite 132
Carnelian 153
Carnotite 191
Cassiterite 221
Cat's eye 153
Cebollite 61
Celestine 143
Celestite 143
Cements 443
  gypsum in 426
  Keene's 430
  materials of 426
  natural 427
  Parian 430
  plaster 430
  Portland 426
  puzzolan 428
  Roman 428
  slag 428
Ceollpa 140
Cerargyrite 233
Cerite 254
Cerium 252
  occurrence 252
  uses 252
Cerium fluoride 252
Cerussite 209
Cervantite 244
Chabazite 58
Chalcanthite 207
Chalcedony 153
Chalcocite 198
Chalcomenite 208
Chalcophyllite 208
Chalcopyrite 200
  crystal form 18
Chalcostibite 208
Chalcotrichite 203
Chalk 386, 438
  uses 386
Charnokite 326
Chatoyant 445
Chemawinite 120
Chemical materials 438
Chert 29, 388
Chiastolite 66
Chili niter 138
Chili saltpeter 138, 438
China clay 56, 381
  uses 382, 434
Chloanthite 178
Chloride of lime 92
Chlorine and its sources 120
  tests for 261
  uses 120
Chlorite gneiss 398
Chlorite group 53
Chlorite schist 396, 403
Chondrodite 68
Chrocoite 168
Chrome green 168
Chrome orange 168
Chrome spinel 155
Chrome yellow 168
Chromic oxide 168
Chromite 168
Chromite bricks 167
Chromium and chromium minerals 167, 168
  tests for 261
  uses 167
Chromium-manganese steel 167

Page
Chromium-molybdenum steel 167
Chromium-nickel steel 167
Chromium ore 168
Chromium phosphate 168
Chromium salts 168
Chromium steel 167
Chromium-tungsten steel 167
Chrysoberyl 150
Chrysocolla 205
Chrysolite 48
Chrysoprase 153
Chrysotile 77
Ciminite 353
Cinnabar 249
Cinnamon stone 64
Cipolin 410
Cipollino 410
Citrine 153
Clastic 445
Clauditite 241
Clausthalite 148, 213
Clay 379, 380, 382, 430, 434, 435
  classification of 431
  composition of 433
  origin 431
  physical properties 432
  products, list of 436, 443
  residual 431
  transported 431
  uses 430, 434, 443
  varieties 379, 380, 381, 431, 432, 434, 435
Clay iron-stone ore 159
Clay rocks 378
Clay slate 400
Cleavage 25
Cleveite 191
Cliche' metal 251
Clino-axis 23
Clinochlore 53
Clinoclasite 208
Clinohumite 69
Clino-pinacoid 23
Clintonites 30, 53
Clinton ore 159
Coal 95, 439
  analyses of 99
  anthracite 100, 387
  bituminous 99, 387
  brown 99, 387
  cannel 106
  classification of 96, 97
  coke, peat, etc. 95
  Colorado 100, 102, 103
  fuel constituents 98
  fuel value 99, 103
  hard 100, 387
  heat value, table 99
  lignite 99
  materials of 96
  origin 96
  products of 104, 107
  sub-bituminous, in Colorado... 102
Coal gas 106, 439
Coal map of Colorado 101
Coal oil 107, 387
Coal slack, for filtering 438
Coal tar 105
  products 105
Cobalt and nickel minerals 175
Cobalt bloom 180
Cobalt blue 175
Cobalt glance 179
Cobalt minerals 181, 179
Cobalt ores 179
  tests for 261
  uses 175
Cobaltine 179
Cobaltite 179

Page
Coke 95, 103, 439
  by-products of 103, 104
  for filtering 458
  manufacture of 104
  natural 116
Coke ovens 103
Colemanite 90, 93, 390
Color, of minerals 28
  minerals grouped by 275
Coloradoite 248, 250
Columbite-tantalite 255
Columbium 252
  uses 252
Columnar 445
Columnar structure 312
Comendite 328
Common rocks 283, 298
Conchoidal fracture 26, 445
Conglomerate 378
Conglomerate gneiss 396
Contact metamorphism 394
Converted saltpeter 137
Copiapite 167
Copper and copper minerals 198-206
  gray 201
  native 199
Copper alloys 198
Copper glance 198
Copper nickel 177
Copper ores 198
Copper-pitch ore 205
Copper, purple ore 201
Copper pyrites 200
  red oxide 203
  tests for 262
  uses 198
  wood 207
  yellow ore 200
Copperas 157, 167
Coral limestone 386
Cordierite 68
Cordierite gneiss 398
Cortlandite 370
Corubin 223, 437
Corundophilite 54
Corundum 81, 225, 437
Cosalite 211, 247
Covellite 204
Creedite 61
Creosote 105
Crinoidal limestone 386
Crocidolite 77
Crocoite 168, 215
Crookesite 148, 226
Crust of earth 9
Cryolite 224, 440
Crypto-crystalline 445
Crystal 12
  combination of forms 13
  constancy of angles 15
  distorted 13
  formation of 12
  habit 13
  ideal 13
  interfacial angle 13
  supplement angle 15
  systems 15-24
Crystal angle 15
Crystal axes 13
Crystal edge 13
Crystal form 13
Crystals and crystal grains 24
Crystalline limestone 384
Crystallization 12
Crystallization of igneous rocks 286, 287
Crystallographic squares 15
Crystallography 12
Cube 15
Cuprite 203
Cuprobismuthite 247
Cuprodescloizite 215

Page
Cuprotungstite 189
Cuprous manganese 173
Cyanides 105, 132
Cyanite 67, 225
Cylindrite 222
Cymatolite 123
Cymophane 150

Dacite 333, 335
Dacite breccia 335, 336
Dacite-obsidian 331, 336
Dacite-perlite 336
Dacite-pitchstone 336
Dacite porphyry 336
Dacite-pumice 336
Dacite, quartz andesite, dellenite group 331, 335, 336
Dacite tuff 336
Danalite 220
Datolite 63
Daubreelite 168
Decrepitate 445
Dellenite 336
Dellenite porphyry 336
Demantoid 65
Dendrites 445
Dendritic structure 445
Dental amalgam 251
Descloizite 195, 215, 220
Desmine 58
Diabase 364, 365
Diabase and basalt group 364
Diabase schist 403
Diallage 42
Dialogite 171
Diamond 93, 94, 151, 437
Diaphaneity 28
Diaspore 225
Diatomaceous earth 388, 437, 438, 440
Dichroite 68
Didymium 252
  uses 252
Dikes 292
Diopside 42, 78
Dioptase 207
Diorite 306, 341
Diorite-andesite family 336, 337
  chemical composition 337
  field classification 340
  mineral composition 338
  occurrence 339
  transitions and relationships 339
Diorite, gabbro 341
Diorite gneiss 396
Diorite group 341
Diorite porphyry 343
Diorite schist 404
Disinfectants, coal tar 105
Ditroite 357
Dodecahedron 16
Dolerite 364
Doleritic breccia, in Colorado 367
Dolomite 73, 93, 384, 442
Dolomitic limestone 384
Domeykite 208
Domes 21, 24
Drift 380, 431
Drusy 445
Dry-bone 216
Ductile 445
Dunite 369, 370
Durdenite 248
Dyestone ore 159
Dyestuffs, coal tar products 105
Dyscrasite 236

Earth's crust 9
Earth materials 9
Earthy fracture 445
Earthy luster 28
Eclogite 404
Effervescence 445

Page
Efflorescent 445
Ekerite 326
Elaeolite 38, 39
Elaeolite syenites 355
Elastic 26, 445
Elaterite 116, 118
Electrical insulation 441
Elements 10
  native 446
  reactions of 258
  union of, in minerals 11
Embolite 92, 234
Emerald 151
  oriental 152
Emerald nickel 178
Emery 81, 437
Emmonsite 248
Emplectite 208
Empressite 235, 248
Enargite 199, 242
Endlichite 194
Engine sand 375
English purple 239
Enstatite 41
Epidote 55, 151
  alteration of 316
Epidote gneiss 398
Epsom salts 128
Epsomite 128
  crystal form 21
Erbia 88
Erythrite 180
Essexite 359
Essonite 64
Eucairite 148
Euchroite 208
Eucryptite, see Beta-Spodumene 123
Even-grained texture 288
Exfoliate 445
Explosives, use of niter in 129
  use of picric acid in 105
Extrusive rocks 298
Eyegrained rocks 287
Fabric of igneous rocks 292
False topaz 153
Feldspars 33, 76, 225, 437, 440
  monoclinic 33
  orthoclase 35
  plagioclase 36
  triclinic 33
  uses 76
Feldspathic quartzite 405
Feldspathic sandstone 377
Feldspathoids 38
Felsite 306, 328, 340, 349
Felsite breccia 341
Felsite-porphyry 306, 340, 350
Felsite tuff 341
Felsitoid group 323, 340, 349
Felsophyre 328
Ferberite 185, 186
Ferrochromium 167
Ferromagnesian 445
Ferromanganese 169
Ferro-nickel 175
Ferrotellurite 248
Ferrotitanium 181
Ferruginous sand 375
Ferruginous sandstone 377
Ferruginous shale 382
Fertilizers 438
Fibrolite 65
Fibrous 445
Fibrous fracture 26
Fichtelite 117
Filiform 445
Filtering materials 438
Filtration sand 375
Fiorite (siliceous sinter) 30
Fire clay 381, 435, 442, 443
  use 382
Fire opal 152

Page
Fire-proofing clay 435
Fire sand 375
Fixed carbon 98
Flagstone 377, 444
Flame coloration 445
Flavoring extracts, coal tar......105
Flax-seed ore 159
Flint 29, 388
  uses 389
Flint pebbles 437
Flooring plasters 430
Flow structure 312
Fluorescence 446
Fluorine and fluorspar 120
  tests for 262
  uses 120
Fluorite 121, 439, 440
Fluxes, list of 439
Foliated 446
Foliated rocks 396
Fossil marble 410
Fossil ore 159
Fossil resin 119
  uses 120
Foyaite 357
Fracture 26
Fragmental group 323, 335, 341
Fragmental rocks 305, 330
Franckeite 222
Franklinite 218
Freibergite 233
Fremontite 125
Freshwater limestone 386
Friable 26
Fuels and illuminants 94
  list of 439
Fuels, heat value of 112
Fullers earth 436, 437, 438
  uses 382, 436, 437
Fusibility, scale of 446
Gabbro 306, 362, 370
Gabbro-basalt family 359
  field and general classification of 362
  mineral composition 361
  occurrence 361
  structural features 361
  transitions and relationships...361
Gabbro-diorite 341, 364
Gabbro-gneiss 396
Gabbro-porphyry 367
Gabbro-schist 403, 404
Gabbro, norite, anorthosite group 362
Gadolinite 88, 253, 257
Gahnite 220
Galena, galenite 208, 236
Galenobismutite 236
Garnet 64, 78, 156
  alteration of 317
  precious 65
  uses 65, 437, 439
  varieties 64
Garnet rock 408
Garnierite 176
Gas, air 439
  coal 105, 106
  composition of coal 106
  from coke making 103, 105
  marsh 108, 111
  natural 111, 387, 439
  occurrence 111
  producer, composition of 107
  uses 111, 112
  water 106, 439
Gas analyses 111
Gaylussite or gay-lussite........141
Gedanite 120
Gem minerals and semi-precious stones 149, 281, 282
  grouped by colors 281
Genthite 178
Gerhardite 208
German silver 175, 198

Page
Gersdorffite 177
Geyserite 29, 388
Gibbsite 223
Gilsonite 117, 387
Glacial clay 380
Glass fiber or wool 438
Glass, materials 439
Glassy group 328, 340, 350
Glass, porcelain, and pottery materials 439, 441
Glassy rocks 288, 305, 307
Glauber salt 138, 390
Glauberite 139
Glaucodot 180
Glauconitic sand 375, 438
Glauconitic sandstone 377
Glaucophane schist 404
Globular 446
Glossary 445
Glucinum 88, 252
  uses 88
Gneisses 396-398
  chlorite 398
  conglomerate 396
  cordierite 398
  diorite 396
  epidote 398
  gabbro 396
  granite 396
  monzonite 396
  peridotite 396
  pyroxenite 396
  quartzite 396
  sillimanite 398
  syenite 396
Gneissoid diorite 398
Gneissoid granite 398
Gneissoid syenite 398
Gold and gold minerals 226
  metallic 227
  tests for 262
  uses of 226
Gooseberry stone 64
Goslarite 220
Gothite 160
Grahamite 116, 387
Granite 305, 322, 340
  binary 326
  graphic 326
Granite gneiss 396
Granite in Colorado 339
Granite porphyry 327
Granite-rhyolite family..318, 324, 325
  mineral composition 320
  occurrence 321
  transitions and relationships...321
  uses 322
Granitic sandstone 377
Granitite 323
Granitoid group 322
Granodiorite 335
Granodiorite-dacite family including quartz monzonite....331
  mineral composition 332
  occurrence 333
  transitions and relationships..333
Granophyre 328
Granulite 398
Graphic granite 326
Graphic tellurium 227
Graphite 93, 100, 387, 441
Graphitic quartzite 405
Gravel 377, 444
Gravel rocks 372
Gravity, specific 27
Gray antimony 243
Gray copper ore 201
Graywacke 377
Greasy luster 28
Greenockite 251
Greensand 375, 377, 438
Greenstone schist 403
Greenstones 403

Page
Green vitriol 157
Greisen 326
Grindstone 378, 437
Grorudite 328
Grossularite 64
Guanajuatite 148
Guano 389, 438
Gumbo 435
Gum copal 120
Gummite 192
Gun-metal 198, 221
Gypsum 72, 79, 93, 390
  occurrence 72, 390
  origin 390
  uses 79, 426, 429, 442, 443
Gypsum fertilizer 438
Gypsum plaster 426

Hackly 446
Hair salt 128
Halite 72, 138, 390
Halloysite 56, 381, 431
Halotrichite 82, 83
Hanksite 141
Hard coal 100, 387
Hard-finish plasters 429, 430
Hardness, scale of 26
Hardystonite 220
Hatchettite 117
Hauerite 173
Hausmannite 173
Hauynite 39
Heat insulation 440
Heavy spar 85
Hebronite 124
Hedenbergite 43
Heliotrope 153
Hematite 158, 159, 160
Herkimer diamonds 154
Hessite 234, 248
Hessonite 64
Hetaerolite 219
Heulandite 57
Hewettite 194
Hexagonal system 18
Hiddenite 78, 123, 151
Hinsdalite 212
Hollow-brick clay 435, 443
Hopeite 220
Hornblende 46
Hornblende andesite 343
Hornblende basalt 366
Hornblende-biotite granite 323
Hornblende dacite 336
Hornblende diorite 340
Hornblende gabbro 306, 364
Hornblende gneiss 396
Hornblende granite 323
Hornblende lamprophyre 354
Hornblende-mica andesite 343
Hornblende-mica diorite 341
Hornblende minette 353
Hornblende norite 364
Hornblende peridotite 370
Hornblende picrite 370
Hornblende-pyroxene andesite 343
Hornblende schist 396, 404
  alteration 404
  varieties of 404
Hornblende syenite 350
Hornblende trachyte 352
Hornblendite 306, 340, 370
Horn quicksilver 250
Horn silver 233
Hornstone 29, 388
Hubnerite 185, 187
Humite 69
Hutchinsonite 226
Hyacinth 151
Hyalite 152
Hyalobasalt 367
Hyalomelan 367
Hyalophane 36

Page
Hyalotrachyte 354
Hydragillite 223
Hydraulic lime 384, 428, 443
Hydraulic limestone 384
Hydrocarbons 93
Hydrocarbons, solid and semi-solid 113, 387, 442
  occurrence 113
Hydro-chlor-platinic acid 236
Hydrogen 263
Hydrogen, disposable 98
Hydromica schist 402
Hydrous chromic oxide 168
Hydrozincite 220
Hyperite 364
Hypersthene 42
Hypersthene andesite 343
Hypersthene basalt 366
Hypersthene diabase 366
Hypersthene gabbro 364

Iceland spar 71, 79
Idiomorphic 446
Idocrase 67
Igneous rocks, classification of 298, 302, 305
  field and general 305
  composition of 283
  extrusive 298
  intrusive 292
  minerals of 29, 49, 51
  occurrence of 292
  structures of 308, 314
Ijolite 359
Illuminants and fuels 94, 439
Ilmenite 161, 183
Impsonite 115
Indian red 158
Indian yellow 222
Indianaite 79, 381, 431, 434
Infusorial earth 388, 438, 440
  occurrence in Colorado 388
  uses 388
Inks 158
Insulating materials, list of 440
Intergrowth 446
Intrusive rocks 292
Intumescence 446
Iodine 263
Iodobromite 92
Iodyrite 235
Iolite 68, 151
Iridescence 446
Iridium 238
  alloys 238
  uses 237
Iridosmine 238
Iron and iron minerals 157
  alloys of 157
  flux, used as 439
  important ores 158
  meteoric 162
  native 162
  ores of 158, 162, 393
  tests for 263
  uses 157, 439, 442
Iron sulphate 157
Isometric system 15

Jade 78
Jamesonite 213, 244
Jarosite 135
Jasper 153, 393
Jelletite 65
Jewel olivine 152
Johannite 198
Jointing 308
Josephinite 162

Kainite 133
Kalinite 82, 134
Kaolin, China clay 381
  uses 434, 442

Page

Kaolin minerals ..56, 75, 79, 431, 440
  rock 434
  uses 381, 382
Kaolinite 56, 75, 225, 431, 440
Keene's cement 430
Keratophyre 328
Kermesite 244
Kerosene shale 110, 118
Kersantite 341, 353
Kidney ore 159
Killinite 123
Kimberlite 370
Knoxvillite 168
Konlite 117
Krennerite 229, 236, 248
Kunzite 78, 124, 151

Labradorite 29, 35, 37
Laccoliths 292
Lake George diamonds 154
Lamellar 446
Laminae 446
Lampadite 173, 181, 204
Lamp black 442
Lamprophyres 353
Land plaster 438
Lanthanum 252, 264
  uses 252
Lapis lazuli 40, 76
Laterite 382
Latite 345, 353
Latite-phonolite 345, 358
Latite-porphyry 345, 353
Laurdalite 357
Laurite 238
Lava rock in Colorado 425
Lazulite 225
Lazurite 40, 76
Lead and lead minerals 208, 213
  alloys of 208
  ores of 208
  paints 442
  salts of 208
  tests for 264
  uses 208
  white ore 209
Lead glance 208
Lead paints 208
Lead sulphate 209
Lead sulphide 208
Leaf-stone 401
Lehrbachite 148
Lenticular 446
Lepidolite 30, 33, 122
Lepidomelane 30
Leucite 38, 225
Leucite, basalt 366
Leucite basanite 359
Leucite phonolite 358
Leucite phonolite-pumice 358
Leucite porphyry 355
Leucite syenite 357
Leucite tephrite 359
Leucitite 359
Leucitophyre 358
Leucophyre 306
Leucopyrite 164
Libethenite 207
Lignite 99, 387, 439
  black 387
  origin of 99
Limburgite 367, 372
Lime 92, 428, 438, 440, 441
Lime, cement, plaster 426, 443
Lime feldspar 34
  uses 428, 439, 440, 443
Limestones 383
  uses 386, 443
  varieties 383-386
Lime uranite 195
Limonite 160
Linarite 215
Linnaeite 180

Page

Liparite 327
Litchfieldite 357
Litharge 208, 440
Lithia mica 30, 122
Lithium and lithium minerals...122
  tests for 264
  uses 122
Lithographic limestone 383
Lithoidite 328
Lithophysae 328
Lithiophilite 124
Lithophone 85, 441
Loam 379
Lodestone 160
Loess 380, 432
Lollingite 164, 242
London purple 239
Lorandite 226
Lubricants 441
Lusters of minerals 28

Macro-axis 21, 23
Macro-dome 21
Macro-pinacoid 21
Magma 446
Magnesia, native 128, 440
Magnesia usta 126
Magnesian limestone 384
Magnesite 126, 441, 442
  uses 127
Magnesium and magnesium minerals 126
  tests for 264
  uses of 126
Magnesium compounds 126
Magnesium-iron mica 30, 31
Magnesium mica 30, 32
Magnetite 159
Magnolite 248
Malachite 202
Malacolite 42
Malacolite rock 408
Malleable 26
Maltha 116, 446
Mammillary 446
Manganblende 172
Manganese and manganese minerals 169, 172
  ores of 169
  tests for 265
  uses 169, 443
Manganiferous iron ores, fluxes..439
Manganite 170
Manganosite 173
Manjak 117
Marbles 406, 409, 410, 443
  Colorado 425
  varieties 392, 409, 410
Marcasite 163
Margarite 53
Marl 386, 438
Marsh gas 111
Massive 446
Martite 165
Materials classified by uses.....437
Materials of cements, limes, plasters 426
Materials of coal 96
Materials of the earth 9
Matildite 236
Matter 9
  organic 9
  inorganic 9
Maucherite 179
Melaconite 203
Melanite 65
Melanochalcite 206
Melanterite 167
Melaphyre 306, 366
Melilite 40
Melilite basalt 370, 372
Melonite 181, 249
Menaccanite 161

Page
Mendozite 82
Mercuric sulphide 249
Mercuric telluride 250
Mercurous chloride 250
Mercury 249, 250
  ores of 249
  tests for 265
  uses 249, 442
Mesolite 60
Metacinnabarite 250
Metahewettite 194
Metaigneous phyllites 401
Metaigneous rocks 395
Metallic meteorite 162
Metallic minerals 157
  uses 157
Metalliferous minerals grouped by color 275
  metallic luster 28
  unmetallic luster 278
Metamorphic minerals 52
Metamorphic rocks 393, 397
  classified 395, 396
  foliated 396
  non-foliated 396
Metamorphism, contact 394
  regional 395
  restricted 394
  weathering 393
Metasedimentary rocks 395
Meteoric iron 162
Meteorites 446
Mexican onyx 392, 409
Miargyrite 236
Miascite 357
Mica 30, 31, 32, 75, 441
  brittle 30
  Colorado localities 76
  crystallization of 30
  uses 75
Mica andesite 343
Mica basalt 366
Mica dacite 333
Mica diorite 341
Mica gabbro 364
Mica group 30
Mica norite 364
Mica peridotite 370
Mica schists 401, 402
Mica slate 400
Mica syenite 350
Mica trachyte 352
Mica trap 353
Micaceous quartzite 405
Micaceous sandstone 377
Micanite 441
Microcline 34, 36
Microgranite 328
Milky quartz 29
Millerite 176
Millstones 437
Mimetite 212, 242
Minargent 184
Mineral, defined 10
Mineral caoutchouc 116
Mineral oil 107, 387
Mineral paint 157
Mineral pitch 114
Mineral tar 116
Mineral wax 116
Mineral wool 440
  associations and occurrences in rocks 28
Minerals grouped by colors .. 275-282
  metallic 157
  metamorphic 52
  nonmetallic 81
  of sedimentary rocks 71
  properties of 12, 25
  resulting from solution 57
  secondary 52
Minette 353
Minium 208, 215

Page
Mirabilite 138, 390
Miscellaneous uses of rocks 426
Misch metal alloys 279, 280
Mispickel 164
Missourite 359
Mizzonite 69
Mock lead 216
Molding sand 375
Molecule 10
Molybdenite 173
Molybdenum and molybdenum minerals 173
  ores of 173
  tests for 265
  uses 173, 443
Molybdenum indigo 173
Molybdenum-nickel 175
Molybdenum steel 174
Molybdenum tannate 173
Molybdenum wire 173
Molybdic ochre 174
Molybdite 174
Monazite 253, 254
Monchiquite 359, 370, 372
Monel metal 175
Monoclinic feldspars 34
Monoclinic system 23
Montanite 249
Monzonite 341, 352
Monzonite gneiss 396
Monzonite porphyries 345, 353
Moonstone 151
Morenosite 181
Morion 154
Morrisite 426, 442
Moss agate 153
Mud 379
Muscovite 30, 31, 76
Muscovite-biotite granite 323
Muscovite granite 323
Muscovite schist 402

Nagyagite 229, 248
Native elements 446
Natramblygonite 125
Natrolite 59
Natron 140
Natural alum, alum clay, alum shale, alum slate 82
Natural cement 427
Natural gas 111, 387, 439
Natural rock cement 384
Natural soda 390
Naumenite 148
Necks and plugs 292
Needle ore 211
Nephelinite 359
Nephelite 38, 225
Nephelite basalt 366
Nephelite porphyry 355
Nephelite syenite 355, 357
Nephelite syenite-phonolite group .354
  analyses 355
Nephrite 78
Nevadite 327
Newtonite 431
Niccoliferous pyrrhotite 176
Niccolite 177, 242
Nicholsonite 219
Nickel and cobalt minerals 175
  alloys of 175
  tests for 266
  uses 175, 443
Nickel steel 175
Nigrine 182
Nigrite 118
Niobium 252, 266
  uses 252
Niter 133
Nitrogen and nitrogen compounds 129, 266
Nivenite 191
Nohlite 256

Page
Nonfoliated rocks 396, 405
Non-metallic 446
Non-metallic minerals and their
    uses 81
Non-metallic minerals grouped by
    color 280
Nordenskioldine 222
Norites 364
Noselite 40
Noumeite 176
Novaculite 393, 437

Obsidian 307, 328
Obsidian-porphyry 307
Ochres 157, 159, 160, 442
Octahedrite 182
Octahedron 15
Oil, asphalt base 108
  classification of 108
  Colorado localities 109
  occurrence 109
  origin 109
  paraffin base 109
  refining 109
  uses 109
Oil shale 382
Oilstones 378, 437
Oligoclase 35, 37
Olivenite 207
Olivine 48
  alteration of 317
  crystalline form 21
  precious or jewel 152
Olivine basalt 366
Olivine diabase 366
Olivine gabbro 362
Olivine norite 364
Olivine syenite 352
Omphacite 404
Onofrite 148
Onyx 154
  calcareous 392
Onyx marble 392
Onyx, Mexican 392
Oolite 392
Oolitic 446
Oolitic limestone 392
Oolitic ore 159
Oolitic quartzite 405
Opalescence 446
Opal 151
Opaque 28, 446
Ophicalcite 409
Ophiolite 409
Orangite 257
Orendite 358
Organ-pipe metal 208
Oriental amethyst 152
Oriental emerald 152
Oriental topaz 152
Ornamental marbles 409
Orpiment 241
Orthite 253
Ortho-axis 23
Orthoclase 33, 34, 35
  crystal form 23
Orthoclase basalt 366
Orthoclase gabbro 364
Ortho-pinacoid 23
Orthorhombic system 21
Osmium 236, 266
  uses 237
Ottrelite 53
Ouvarovite 65
Oxidizing flame O. F. 446
Oxygen 130, 266
Ozokerite 116, 387

Paint and pigment materials ...441
Paint clay 436
Paisanite 328
Palladium 239, 266
  alloys of 239
  uses 237

Page
Pandermite 90
Pantellerite 328
Paper clay 435
Paper-making materials 441
Paraffin, native 116
Paragonite 30, 33
Parasite 89
Parian cement 430
Paris green 239
Paris purple 239
Parisite 257
Partinium 184
Patronite 192
Paving-brick clay 435
Paving blocks 444
Pea ore 159
Pearceite 236
Pearl sinter 29
Pearl spar 74
Pearly luster 28, 446
Peat 95, 99, 387, 439
  origin 99
Pectolite 63
Pegmatite 326
Penninite 54
Pentagonal dodecahedron 16
Pentlandite 177
Percussion figure 446
Perfume, from coal tar 105
Peridot 48, 152
Peridotite 306, 370
Peridotite gneiss 396
Peridotite, pyroxenite-limburgite
    augitite and related rocks 367
  alteration of 369
  field and general classification.369
  mineral composition 369
  occurrence 369
  texture 369
  transitions and relationships...369
Perlite 307, 330
Petalite 126
Petroleum and its products.......
  ....107, 387, 439
  asphalt base 108
  classification of 108
  Colorado localities 109
  flash test 110
  occurrence 109
  origin 109
  paraffin base 108
  products of 107
  refining of 88, 109
  uses 109
Petzite 229, 236, 248
Pewter 208
Phanerites 305
Phanerocrystalline 292
Pharmacosiderite 166
Phenacite 152
Phenocryst 446
Phlogopite 30, 32, 76
Pholerite 431
Phonolites 358
Phonolite breccia 358
Phonolite-obsidian 358
Phonolite-pitchstone 358
Phonolite, tinguaite group 357
Phonolite tuff 358
Phosgenite 214
Phosphate rock 131, 389, 438
Phosphor-bronze 198
Phosphorite 389
Phosphorus and phosphorus
    minerals 130
  tests for 267
  uses 130
Phosphorus bronze 221
Photographic preparations, coal
    tar 105
Phyllite 398, 401
  metaigneous 401
Phyllite slates

Page
Pickeringite 82
Picotite 155
Picric acid 105
Picrite 370
Picrite porphyry 370
Picromerite 135
Pigments and paint materials 441
Pigments, iron 157
Pinacoids 18, 19, 21, 23, 24
Pintadoite 194
Pipe clay 380
Pisolitic 446
Pitchblende 190
Pitchstone 307, 328
Pitchstone porphyry 307
Pittasphalt 116
Plagioclases 33, 36
Plasma 153
Plasters 426
Plaster board 430
  cement 430
  flooring 430
  hard finish 430
  materials of 426
Plaster of Paris, uses, etc. 79, 429, 443
Plaster, wall 429
Platinoid 184
Platinum 237
  sources 237
  tests for 267
  uses 236
Plugs and necks 292
Plumbago 93
Polianite 172
Polyargyrite 236
Polybasite 233
Polyhalite 134
Porcelain, materials 440
Porcellanite 394
Porphyrite 345
Porphyritic 446
Porphyritic svenite 340, 352
Porphyritic texture 288
Porphyroid 401
Portland cement 426, 435, 443
Portland cement clay 435
Potash alum 134
Potash feldspar 34
Potash mica 30, 32
Potassium and potassium minerals 131
  tests for 268
  uses 131
Potassium chloro-platinate 236
Potassium nitrate 133, 440
Potassium salts 131, 132, 438
  uses 438
Potassium tungstate 185
Pottery, materials 440
Powellite 175
Prase 154
Prehnite 62
Priceite 90
Prisms 16, 19, 23, 24
Producer gas 107, 439
Properties of minerals 12
Propylite 345
Proustite 231, 242
Prussian blue 158, 222
Pseudoleucite syenite 357
Pseudomorph 446
Psilomelane 170
Puddingstone 378
Pulpstones 378, 437
Pumice 307, 323, 330, 437, 439
  uses 330
Purple copper ore 201
Putty 79
  coat 429
Putty powder 437
Puzzolan cements 428, 443

Page
Pyramids 16, 19, 23, 24
Pyrargyrite 231, 244
Pyrite 162, 200, 236
Pyritohedron 16
Pyrochroite 173
Pyrolusite 169
Pyromorphite 210
Pyrope 65
Pyroxene 43
  alteration of 317
  crystal form 23
Pyroxene andesite 343
Pyroxene gneiss 396
Pyroxene granites 326
Pyroxene group 41
Pyroxenes and amphiboles 40
  uses 77
Pyroxenite 306, 367, 369, 370
Pyroxenite gneiss 396
Pyrrhotite 164, 200

Quartz 29, 71, 75, 136, 437
  crushed 439
  crystal form 19
  flux, use as 439
  uses of 75, 153, 439, 442
Quartz and silica minerals 30
Quartz andesite 333, 336
Quartz-augite diorite 333, 335
Quartz basalt 366
Quartz bostonite 328
Quartz diabase 366
Quartz diorite 333
Quartz diorite porphyry 333, 335
Quartz feldspar porphyry 327
Quartz gabbro 364
Quartz keratophyre 328
Quartz-mica diorite 333, 335
Quartz, milky 29
Quartz monzonite 331, 335
Quartz monzonite porphyry 335
Quartz norite 364
Quartz porphyrite 328
Quartz porphyry 327
Quartz sandstone 377
Quartz syenite 352
Quartz tinguaite 328
Quartzite 396, 405
  feldspathic 405
  graphitic 405
  micaceous 405
  oolitic 405
  transitions 405
Quartzite gneiss 396
Quick lime 428
Quicksilver 249, 250
  horn 250

R 446
Radiated 446
Radiolarian ooze 388
Radium 87
  Colorado localities 87
  uses 87
Ragged fracture 26
Ramirite 215
Rammelsbergite 181
Reactions 446
Realgar 239
Rectorite 431
Red copper oxide 203
Red hematite 158
Red lead 215, 440
Red oxide of zinc 217
Red zinc ore 217
Redingtonite 168
Reducing flame, R. F. 446
Reduction 446
Refractory materials 442
Regional metamorphism 394, 395
Resinous luster 28
Retarders 430
Retinite 120

Page
Rhodochrosite 171
Rhodonite 45, 78
Rhombic dodecahedron 16
Rhombohedron 19
Rhyolite 327
Rhyolite breccia 323, 331
Rhyolite flow-breccia 331
Rhyolite glass 328
Rhyolite group 326
Rhyolite porphyry 327
Rhyolite tuff 323, 330
Rickardite 206, 248
Riebeckite 47
Road materials 426, 444
Rock, defined 10
Rock crystal 154
Rock-making minerals 29
  alteration of 314
  uses 75
Rock oil 107
Rock salt 390
Rockallite 326
Rocks, chiefly chemical precipitates 390
  common 283
  composition of 10
  igneous, origin, etc. 283
  metamorphic 393, 397
  miscellaneous uses of 426
  occurrence of minerals in 28
  sedimentary 372
Roman cement 428, 443
Roscoelite 30, 33, 193
Rose quartz 154
Rothoffite 65
Rotten stone 437
Rouge 437
Rubellite 154
Ruby 154
  oriental 154
Ruby silver ore 231
Ruby spinel 155
Ruin marble 410
Rutilated quartz 154
Rutile 181

Sagenite 154
Salicylic acid 105
Salines 442
Salt 136, 137, 138
Salt cake 439
Saltpeter 133, 138
Samarskite 253, 256
Sand and gravel rocks 372
Sand 372, 375, 439
  black 375
  varieties and uses 375, 377
Sandstone 377, 378, 443
  Colorado localities 425
Sandstone breccia 378
Sand-lime bricks 429
Sandy limestone 383, 386
Sandy shale 381
Sanidine 36
Sanitary ware 444
Sapphire 81, 154
Sapphire quartz 154
Sard 153
Sardonyx 154
Sassolite, sassolin 91
Satin spar 79
Scalenohedron 19
Scapolite 69
Scheele's green 239
Scheelite 187
Scheererite 117
Schists 401-405
Schoenite 135
Schorlomite 65
Scolecite 60
Scoria 330
Scorodite 166

Page
Secondary or metamorphic minerals 52
Secondary minerals, dynamic 64
Secondary minerals, from solution 57
  from weathering 52
Sectile 446
Sedimentary rocks 372
  calcareous 382
  carbonaceous 387
  minerals of 71
  organic origin 382
  phosphatic 389
  siliceous 387
Selenite 79
Selenium 147
  sources 147
  tests for 268
Selen-tellurium 148, 249
Semi-solid hydrocarbons 113, 387
Sericite 31
Sericite schist 402
Serpentine 52, 410
  fibrous 77
  uses 77, 410
Serpentine marble 409
Serpentine rock 370, 410
Serpentine, soapstone, and
  sewer-pipe clay 410, 435
Shale 381, 382
  alum 382
  oil 110, 382
Sheets, intrusive 292
Shell marble 410
Shell marl 386
Shonkinite 350
Sideraphite 183
Siderite 161
Siennas 157
Silica 136
  uses 439, 440, 442
Siliceous oolite 393
Siliceous ooze 388
Siliceous rocks 387
Siliceous sand 375, 442
Siliceous sinter 29, 388
Silicon and silicon-bearing minerals 135
  tests for 268
  uses 135, 443
Silky luster 28
Sillimanite 65
Sillimanite gneiss 398
Silver and silver minerals 229, 234
Silver-bearing galena 230
Silver-bearing minerals, other 236
Silver, brittle ore 232
  dark red ore 231
  horn 233
  light red ore 231
  metallic 229
  ruby ore 231
  tests for 269
  uses 229
Silver glance 230
Slacked lime 92
Slag, basic 438
Slag cement 428
Slate, varieties, uses, etc. 398, 400, 401, 441, 442, 443
Slip clay 435, 440
Sludge 438
Smalt blue 175
Smaltite 178, 242
Smithsonite 216
Smoky quartz 154
Smoky topaz 154
Smooth fracture 26
Soapstone 55, 396, 411, 441
Soda ash (See Sodium sulphate).
Soda, natural 140, 390
Soda feldspar 34

Page
Soda niter 138
Soda orthoclase 34, 35
Soda-lime feldspars 34
Sodalite 39
Sodalite rock 359
Sodalite syenite 357
Sodium and sodium minerals 136
  tests for 270
  uses 137
Sodium minerals 138-142
Sodium nitrate 138, 438
Sodium salts 136, 137, 438, 439
Sodium sulphate 137, 139, 439
Soils 379
Solder 208, 220, 251
Solid hydrocarbons 113, 387
Soundproofing materials 440
Spangolite 208
Spar, brown 74
  calc 71
  Iceland 79
  pearl 74
  satin 79
Specific gravity, table of 27
Specular hematite 159, 263
Sperrylite 238
Spessartite, spessartine 65
Spiegeleisen 169
Sphalerite 216, 236
Sphene 49
Sphenoid 18
Spheroidal sundering 312
Spherulitic structure 314
Spinel 154
  chrome 155
  ruby 155
Spodumene 78, 122
Stalactite 392, 446
Stalagmite 392
Stannic chloride 221
Stannite 221
Star quartz 154
Star sapphire 154
Stassfurtite 89
Statuary bronze 198
  marble 409
Staurolite 70, 78, 154
  crystal form 21
Steatite 55, 411
Steel 157
  crushed, use of 437
Steel-cleansing materials 443
Steel-hardening materials 443
Stephanite 232, 244
Stibiconite 244
Stibnite 243
Stilbite 58
Stocks and bosses 298
Stolzite 188
Stone, crushed 444
Stoneware clay 435
Streak 28
Striations 446
Strike figures 446
Stromeyerite 231
Strontianite 143
Strontium and strontium minerals 142
  tests for 270
  uses 143
Structural materials, list of 443
Structures of igneous rocks 308
Stucco 430, 440, 443
Sublimate 446
Sublimed blue lead 208
Sublimed white lead 208
Subvitreous 447
Succinite 119
Sugar of lead 208

Page
Sulphur and sulphur-bearing minerals 144, 145, 146
  crystal form 21
Sulphur dioxide 145
Sulphur trioxide 145
Sulphuretted hydrogen 145
Sulphuric acid 144
Superphosphates 131, 438
Sussexite 359
Syenite 305, 340, 362
Syenite-aplite 352
Syenite gneiss 396
Syenite group 350
Syenite-pegmatite 352
Syenite porphyry 352
Syenite-trachyte family 347
  mineral composition 348
  occurrence 349
  transitions and relationships .. 349
  uses 349
Sylvanite 22, 236
Sylvite 132
Symbols of elements 258

Tabbyite 118
Tachylite 367
Talc 55, 441, 442
Talc schist 396, 403
Tantalite 253, 255
Tantalum 252, 271
  uses 252
Tar, coal, and products 105
  mineral 116
Tarnish 447
Tawite 359
Teallite 222
Telluride, mercuric 250
Tellurite 248
Tellurium and tellurium minerals 247, 248
  native 248
  tests for 271
  uses 247
Tenacity 26
Tennantite 202, 242, 252
Tenorite 203
Tephrite 359
Terra-cotta, clay 435, 443
Teschenite 359
Test paper 447
Tetradymite 247, 248
Tetragonal system 16
Tetrahedrite 201, 244
Textural terms 288
Textures of rocks 285
Thallium 225, 271
Thenard blue 222
  yellow 222
Thenardite 141
Theralite 359
Thermonatrite 141
Thomsonite 61
Thorianite 253, 256
Thorite 253, 256
Thorium 252, 271
  uses 252
Thorogummite 192
Thulite 51
Tiemannite 148
Till 380, 431
Tilkerodite 148
Tincal 88
Tinguaite 358
Tinguaite, phonolite group 357
Tin and tin minerals 220, 222
  alloys 220
  tests for 271
  uses 220

Page
Tin oxide 221
Tin pyrites 221
Titanic iron ore 161, 183
Titanite 49
Titanium and titanium minerals..181
  alloys of 181
  tests for 272
  uses 181, 443
Titanium ferrocyanide 181
Tonalite 335
Topaz 155, 225
  false 154
  oriental 152
Topazolite 65
Torbanite 110, 118
Torbernite 195
Tordrillite 328
Tourmaline 50
Trachydolerite 353
Trachyte 352
Trachyte breccia 354
Trachyte-obsidian 328, 354
Trachyte-perlite 354
Trachyte porphyry 352
Trachyte-pumice 354
Translucent 28
Transparent 28
Trapezohedron 16
Travertine 392
Tremolite 45, 78
Triclinic feldspars 34
Triclinic system 23
Triplite 165
Triphylite-lithiophilite 124
Tripoli 389, 437, 439
Tritochorite 215
Trona 140, 142, 390
Troostite 218
Tschermigite 82
Tuffs and breccias 307
  andesitic 345
  basaltic 307
  dacite 335
  felsite 307
  rhyolite 307
  trachytic 354
Tungsten and tungsten minerals 183, 188
  alloys of 183, 184
  tests for 272
  uses 183
Tungsten bronze 184, 443
Tungsten-nickel steel 175
Tungsten ores 185
Tungstic ochre 188
Tungstite 188
Turgite 161
Turmeric paper 447
Turquois, turquoise 156, 225
Twinning of crystals 15
Type-metal 208
Tysonite 257
Tyuyamunite 192

Uintaite 117
Ulexite 90
Ullmannite 181
Ultramarine, artificial 77, 442
  native 40
Umbers 157
Uraconite 198
Uraninite 190
Uranium, vanadium, and their minerals 189, 195, 198
Uranium and vanadium ores 190
Uranium and vanadium ores of western Colorado 196
Uranium carbide 189
Uranium, tests for 192, 272
  uses of 189, 443
Uranocircite 198
Uranophane 195
Uranopilite 198
Uranosphaerite 195
Uranospinite 198
Uranothalite 198
Urao 140, 390
Urtite 359
Uvanite 194
Uvarovite 65

Valentinite 244
Vanadic ochre 198
Vanadinite 193
Vanadium, uranium, and their minerals 189
Vanadium, tests for 196, 273
  uses 190, 443
Vanadium mica 30
Variegated copper ore 201
Variolite 367
Venetian red 158
Verd antique 409
Verite 345
Vesicular structure 312
Vesuvianite 67
  crystal form 18
Vietinghofite 256
Vitreous luster 28, 447
Vitrophyre 307
Vivianite 165
Vogesite 353
Volatile hydrocarbons 98
Volborthite 197
Volcanic ash 298, 439
Volcanite 336
Voltzite 220
Vrbaite 226
Vulsinite 353

Wad 172
Wall plaster 429
Walpurgite 198
Water gas 106, 439
  composition 106
Ware clay 434
Wax, mineral 116
Weathering, agencies of 314
Weathering, minerals resulting from 52
Websterite 84, 370
Whetstones 378, 437
Wernerite 69
White iron pyrite 163
White lead 442
  Dutch, French and English 208
  ore 209
White mica 31
Whiting 79, 442
Whitneyite 208
Willemite 218
Witherite 86
Wolfram 186
Wolfram-aluminum 184
Wolframite 185, 186
Wolftonite 219
Wollastonite 70, 93
Wood copper 207
Wood opal 152
Wulfenite 174
Wurtzilite 117, 118, 387
Wurtzite 219
Wyomingite 358

Page
Yellow copper ore 200
Yttrium 88, 252, 273
uses 252

Zaratite 178
Zeolites and related minerals.....57
Zeunerite 196
Zinc and zinc minerals 216
red ore, red oxide 217
uses 216
Zinc blende 216
Zinc carbonate 216
Zinc pigments 216, 437

Page
Zinc salts 216
Zinc spinel 220
Zincite 217
Zinkenite 214, 244
Zinnwaldite 30
Zircon 49, 78, 257, 437
crystal form 18
uses 78
Zircon syenite 357
Zirconia 78
Zirconium 252
tests for 274
uses 252
Zoisite 51

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