With the best
regards of R. A. George

UNIVERSITY OF COLORADO SEMICENTENNIAL SERIES

1877-1927

UNIVERSITY OF COLORADO

SEMICENTENNIAL PUBLICATIONS

Authorized by the Board of Regents of the University of Colorado and prepared under the supervision of a committee of the Faculty consisting of William R. Arthur, George F. Reynolds, Oliver C. Lester, Herbert S. Evans C. Henry Smith, and Maurice H. Rees, these five volumes are issued as part of the celebration of the Semicentennial of the University, November, 1927 They will be of interest primarily to the people of this State and are appropriately

DEDICATED TO
THE CITIZENS OF COLORADO

GEOLOGY AND NATURAL RESOURCES
OF COLORADO

Lou. D. Sweet
Denver
Colo
Recd 11/10/27

BY

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PREFACE

This little book is an attempt to bring within the compass of a small volume a discussion of several subjects, each of which is worthy of the space available for all. The necessary condensation has doubtless led to a disproportionate allotment of space, and an inequality of emphasis which it is hoped will be overlooked.

The geology of Colorado is written in the rocks. From this great book are here presented translations of a few paragraphs. The scenery of Colorado is a gallery incomparable. Words lack form and light, color and life—the essence and soul of scenery. At best they can but call attention to the elements associated in the picture. They cannot convey the beauty and harmony of the assemblage.

The climate of Colorado may be compared to a tapestry, woven from sunshine and cloud, wind and temperature. Tables and data cannot present the qualities and charm of the blending of these elements in the days and the seasons. The physical resources of the state appeal to the practical side of the people, and prophecy is asked of him who would write about them—a declaration of the present and a promise of the future.

Grateful acknowledgment is here made to Professor Herbert C. Hanson, of the Colorado Agricultural College, for the substance of the pages on pasture lands and forage plants; to the National Forest Service and the State Forester for assistance in the too brief discussion of the timber resources and their conservation; to Professor Keser for notes on Colorado soils.

The State Historical and Natural History Society kindly permitted the expansion and use of a chapter prepared by me for the Society's History of Colorado.

Many published reports have been drawn upon in the preparation of the book, and specific references would be impossible. A worthwhile bibliography of the subjects discussed would be too voluminous.

The unvarying patience of the Semicentennial Committee is fully appreciated, and if the readers of this book are equally tolerant the writer will be highly gratified.

Boulder, Colorado,
October, 1927.

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INTRODUCTION

Geology is a history of the earth. The historian of a nation seeks the original documents, the ancient monuments, the institutions and even the traditions of the people whose history he would write. He finds in the past the key to the present, and in the present the natural consequence of the past. He brings together the materials of the past not as isolated, unrelated facts but as the warp and woof, the design, the coloring and the motive of a great tapestry, which becomes the living background and the stage itself on which is being enacted the drama of today.

The historian of the earth is equally dependent upon the past. He must seek the original documents—the rocks, their structures, the life records, the forces which produced the condition he finds. The records of the rocky pages are incontrovertible —unaffected, unaltered by national pride, hero-worship, hatred and jealousy. There is but one record—no conflicting transcriptions and translations, no conflicting motives of ancient chroniclers.

In earth history as in human history the light of the past fades into twilight and night, and the farther we seek the dawn the more impenetrable becomes the darkness.

In geological history there is a time when the light decreases with baffling suddenness, and though much the greater part of earth history preceded that time, the volume of our knowledge of that history is exceedingly limited, and the certainty of interpretation is small. We might call this time the dividing line between the unknown and the known—between the unknowable and the knowable, for there is but little hope of adding greatly to our knowledge of the almost limitless pre-Cambrian ages.

There is but one comprehensive geologic record—a very complex one. The great continental masses are the libraries, but so far as we know not one of these contains the complete story, and it must be pieced together by careful study, comparison and correlation. If the continental records are incomplete, how much more so would be the story as told in the rocks of a single state such as Colorado.

The incompleteness of the record is due to the instability and changeableness of the earth. Even the mountains are but temporary features in the long earth history, and in the past many ranges have appeared and disappeared. Many subsidences and elevations of the land, many warpings and tiltings have caused countless changes in the relations of land and sea.

> "There rolls the deep where grew the tree.
>   O earth, what changes hast thou seen!
>   There where the long street roars, hath been
> The stillness of the central sea.
>
> The hills are shadows, and they flow
>   From form to form and nothing stands,
>   They melt like mists, the solid lands,
> Like clouds they shape themselves and go."
>
> —Tennyson.

These changes have controlled in large measure the writing of the most legible part of the earth story.

The greatest chronicler of earth history is water—chiefly marine or sea water, but land waters have played their part. The atmosphere, volcanic phenomena, climatic conditions and many other agents have added to the records but in a less important measure. And so the geological story of Colorado will be told largely in the changing relations of land and water. When water occupied part or all of the surface of the state, history was recorded in readily legible characters. When the area of the state was entirely land it was as though the pen had been lifted from the page, and we must seek the connecting links of the story, the lost act or scene of the play, elsewhere.

Just as human history is divided into eras, periods, epochs and ages by the rise and fall of races and peoples, so the local geological history of the earth is marked by events and changes which may serve to set off one part of geological time from another. As there have been very few events in human history which have involved the whole human race, so there have been few geological events which have affected the whole earth, or even a whole continent. One region may pass through a period of upheaval and mountain building while another part of the same continent may be undergoing a depression which allows the sea to cover vast areas once occupied by dry land. While volcanoes may be burying forests and fields under molten lava in one part of a continent, glacial ice may be accumulating in another region at no great distance.

Students of geology, the world over, have accepted the main subdivisions of geological time adopted by the pioneers of the science in Europe. Later study has shown that these subdivisions are not readily recognized in all parts of Europe and have but a limited application to the geological history of America. At the same time, though these divisions of geological time are, for many parts of the earth, purely artificial, probably no other dividing lines could have been chosen which would have been based on more widespread geological events. They are universally adopted because they serve the useful end of grouping life forms and geological events for the purposes of world wide study and comparison.

The history of life on the earth is the story of the development of plants and animals from simpler to more complex forms. It is true that some ancient types still live, connecting the remote past with the present, but if we could compare the life of the earth today with that of early geological time, the differences would impress us much more strongly than would the likenesses. And yet if we could have before us a grand procession representing the life of all geological ages from the dawn of life on the earth to the present time we should be impressed by the gradual development from the earlier and more primitive forms to those of the present time. We should find no great breaks or abrupt changes marking the passage from one geological era to another—no sudden appearance of new and unexpected forms—but a gradual unfolding and upbuilding. This is very well illustrated by the evolution of the horse, whose development from an animal not larger than a house cat to his present size occupied millions of years. But in all that time there were no abrupt changes, but rather a slow, steady progress toward the present form.

The history of life on the earth might be compared to the current of a river—unbroken from the mountain springs to the ocean. The rate of flow varies from place to place through pools and eddies in which motion is scarcely measurable, then past narrows and over rapids where it is strong and swift. So the rate of life development was at times sluggish, at times rapid, depending upon climate, food supply, density of population and other local conditions.

The divison into eras is based on the broad, general features of the development of life as revealed by the study of fossils and other evidences of life contained in the rocks. The divison of the eras into periods does not follow any rule. Several periods are named from the regions in which the rock systems of those periods were first studied, or most satisfactorily interpreted. The name Cambrian is from "Cambria," the Latin name for Wales. Ordovician and Silurian come from "Ordovices" and "Silures", the names of two ancient British tribes. Devonian is from the county of Devon in southwestern England. The Carboniferous period is so named on account of the great amount of carbon (in the form of coal), contained in the rocks of that period. The Triassic is named from the threefold division of the rocks of the period in Germany. The Jura Mountains furnish us the name Jurassic. The Cretaceous is so named from the abundance of chalk (creta) in the rocks of that period, in England.

The larger subdivisions of geological time, as used in America, are shown in the following table.

Geological Time Table

Era			*Period*	
	Cenozoic (New Life)	Quaternary	Recent	
			Pleistocene	
		Tertiary	Pliocene	
			Miocene	
			Oligocene	
			Eocene	
	Mesozoic (Middle Life)		Cretaceous	UpperCretaceous
				LowerCretaceous
			Jurassic	
			Triassic	
	Paleozoic (Old Life)		Permian	
			Pennsylvanian (Upper Carboniferous)	
			Mississippian (Lower Carboniferous)	
			Devonian	
			Silurian	
			Ordovician	
			Cambrian	
		Great Interval		
Pre-Cambrian	Proterozoic (Dawning Life) Algonkian		Keweenawan	
			(Interval)	
			Upper Huronian	
			(Interval)	
			Middle Huronian	
			(Interval)	
			Lower Huronian	
			(Great Interval)	
	Archeozoic (Ancient or First Life) Archean		Keewatin	
			Laurentian	
			The great Archean complex of granites, gneisses, schists, slates, quartzites, etc.	

Chapter I

ROCKS AND MINERALS, TOPOGRAPHY AND DRAINAGE

ROCK TYPES

There are three general rock types recognized by geologists:

1. Igneous rocks are those which have solidified from a molten condition.

2. Sedimentary rocks are those derived by processess of decay and wear of pre-existing rocks. The materials resulting from such processes are carried from their place of origin and deposited elsewhere chiefly by water and in water, though wind may carry and deposit the finer and lighter materials, such as sand and dust.

3. Metamorphic rocks are those which have been formed by the profound alteration of igneous or sedimentary rocks. The chief agencies producing such alteration are heat, water, pressure and movement.

Most rocks are composed of minerals, and though there are thousands of minerals known to geologists only a few are important in the makeup of rocks. The three rock types have their characteristic minerals, but some are found in all types.

If molten rock matter cools and solidifies very slowly it is commonly completely differentiated and crystallized into mineral grains, and the texture is fairly coarse. If it cools more rapidly it may be wholly differentiated and crystallized into mineral grains, but they will be small and the rock is fine textured. Rapid cooling will form a rock which may be only partly crystalline and partly glassy, or wholly glassy.

The lavas poured out of volcanoes or fissures are fine textured and often glassy because of rapid cooling. Granites are coarse textured because they cooled slowly under the protecting cover of other rock masses.

The commonest rock-making minerals of the igneous rocks are: Feldspar, quartz, mica, hornblende, pyroxene, olivine and the oxides of iron.

The minerals of the sedimentary rocks are:
Quartz in the form of sand.
Feldspar in fragments and sand.
Calcite or lime carbonate.
Gypsum or lime sulphate.
Kaolin which is an important constituent of clay rocks.
Magnetite is present in most sedimentary rocks.

Feldspar is a silicate of aluminum with potash, soda or lime. It is commonly pink or milk white and is by far the most important mineral of igneous rocks.

Quartz as a rock-making mineral is generally in irregular grains, is very hard and has a glassy luster.

Mica is readily recognized by its perfect cleavage into thin, smooth, shiny flakes. There are two common micas. Muscovite is white or silvery. Biotite is black.

Hornblende and pyroxene are closely related minerals which cannot be readily distinguished in the rocks. The commoner forms of these minerals are greenish gray to iron gray or black. They do not glisten as does the black mica and are usually in longer grains of fibrous appearance.

There are pale green and grayish green fibrous hornblendes and fibrous bronzy pyroxenes.

Olivine is a rather rare glassy mineral of yellowish green color.

The commonest iron minerals are the heavy black magnetite, and the brass-yellow pyrite.

Calcite is a colorless to white mineral with a good cleavage. It is the granular mineral of marble. It is soft and easily scratched.

Gypsum is a white granular mineral, soft and easily cut with a knife.

Garnet is a common mineral in metamorphic rocks. It is very hard, resists weathering, and is generally easily recognized by its garnet red color and glassy luster.

The micas, hornblendes and quartz are important minerals in the schists and gneisses.

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 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 very ancient rocks, and are frequently in contact with schists and gneisses. Batholithic outcrops are numerous in a zone extending from Boulder County southwest to the San Juan.

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.

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

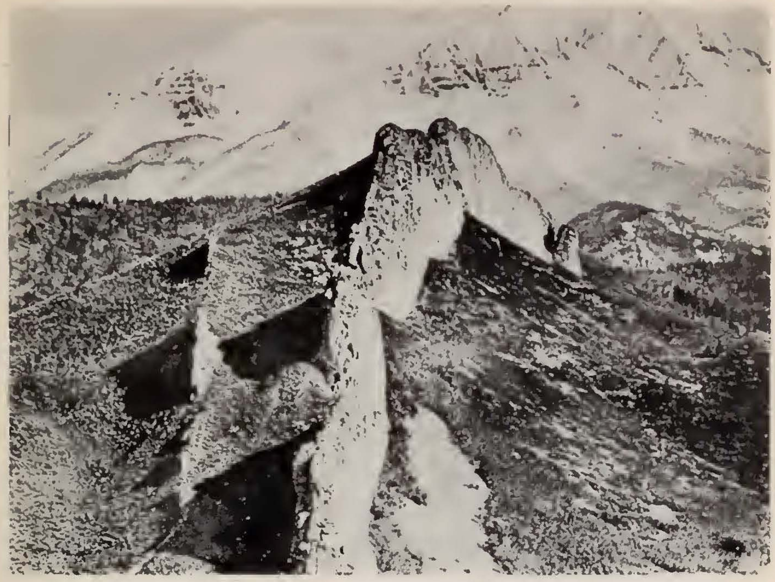
(*See Illustrations Pages 5 to 25*)

I. GRANITOID ROCKS: All rocks whose mineral grains are large enough to be recognized by the unaided eye.

II. FELSITOID ROCKS: Rocks composed mainly or entirely of mineral grains so small that they cannot be 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 or glassy 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.

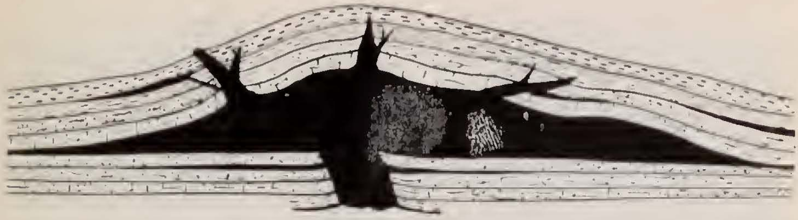


Dikes
Spanish Peaks, Colo.

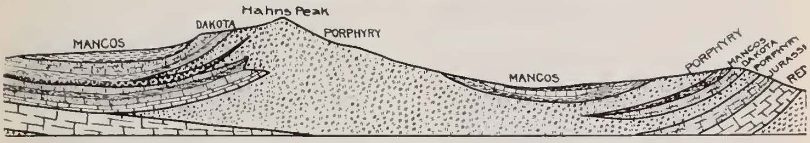
Basic dikes in light colored quartzite

Sheet of columnar basalt

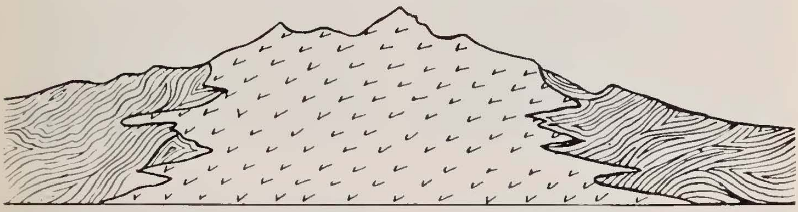
Volcanic neck or plug Yampa Valley, Colo.



Section through a laccolith before erosion

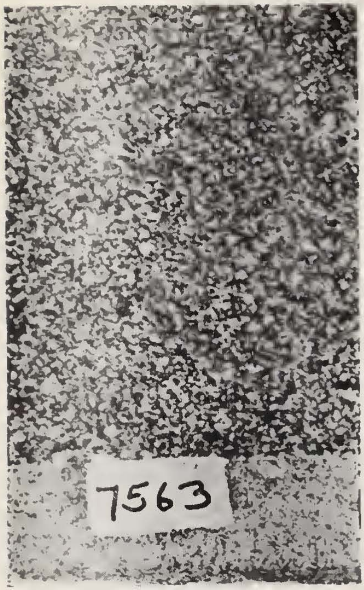


Section through an eroded laccolith
Hahn's Peak, Colo.



Section through a batholith

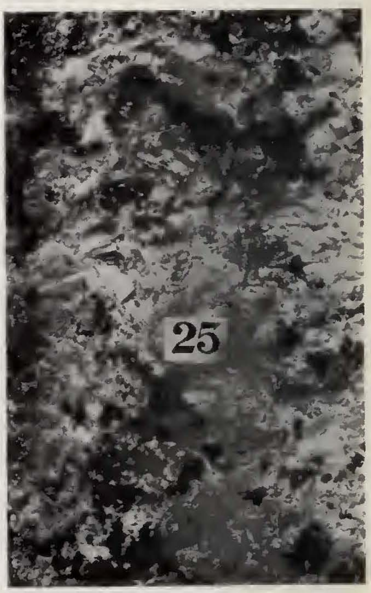
Series of lava flows



Granitoid, fine texture

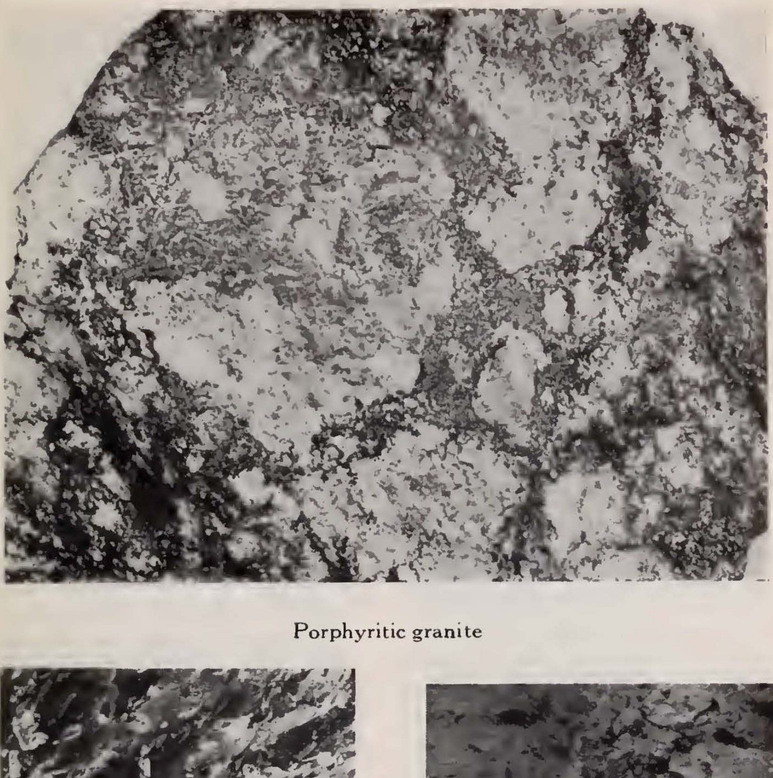
Granitoid, medium texture

Granitoid, coarse texture



Granitoid, uneven texture

GRANITE GROUP

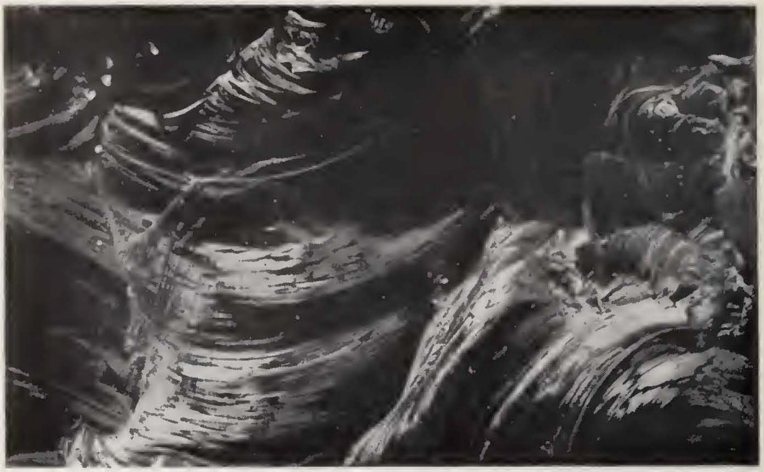


Porphyritic granite

Quartz-feldspar porphyry

Syenite porphyry

GRANITE GROUP



Glassy texture obsidian

Glassy and porphyritic texture
pitchstone porphyry
Georgetown, Colo.

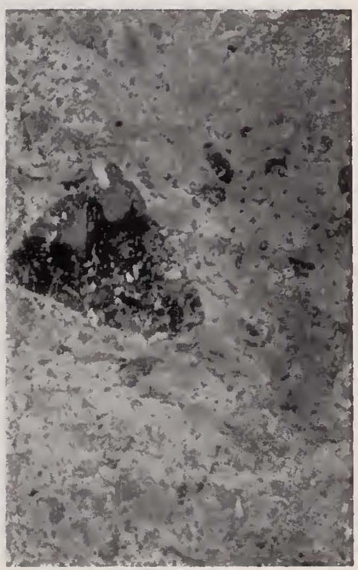
Felsitic texture
felsite
Boulder, Colo.

GRANITE GROUP

Graphic granite

Pumice

Rhyolite tuff



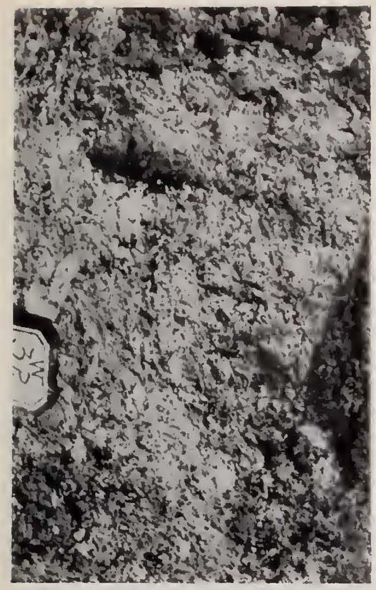
Rhyolite breccia

Syenite

Syenite

Monzonite
Silverton, Colo.

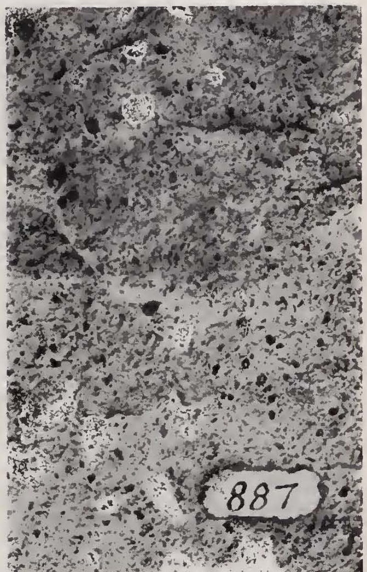
Quartz monzonite
Chaffee Co., Colo.



Trachyte

Trachyte
showing flow structure

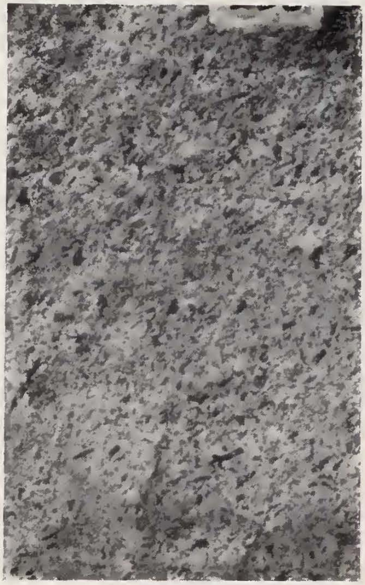
Hornblende latite
Silverton, Colo.



Quartz latite
Silverton, Colo.

Nephelite syenite
Cripple Creek, Colo.

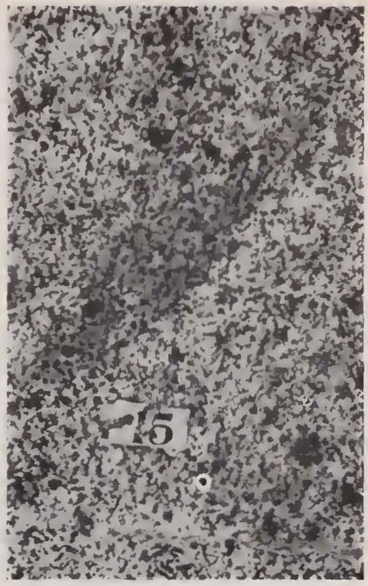
Nephelite syenite, coarse



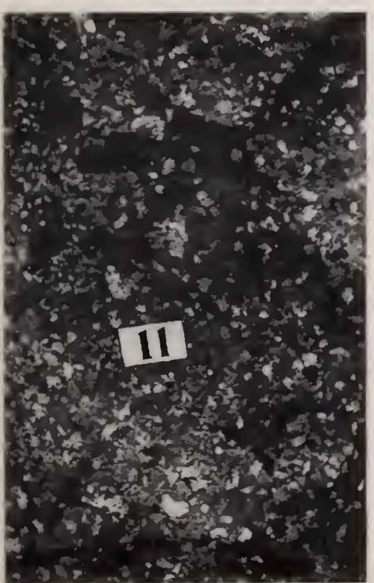
Phonolite
Cripple Creek, Colo.

Vesicular phonolite
Cripple Creek, Colo.

Diorite



Diorite



Andesite


Porphyritic andesite

Andesite breccia
Cripple Creek, Colo.

Andesite tuff

Gabbro

Hornblende gabbro

Dolerite
Valmont, Colo.

Basalt

Pyroxenite

Peridotite

SUBDIVISION OF THE GROUPS

I. Granitoid Rocks

1. GRANITE: Chief minerals are Feldspar and Quartz. Subordinate minerals may include mica, hornblende, pyroxene. Granite porphyry may be included.

2. SYENITE-MONZONITE: Chief mineral is Feldspar. Subordinate minerals may include quartz, mica, hornblende, pyroxene and nephelite.

3. DIORITE: Chief mineral is Hornblende. Subordinate minerals are mica, feldspar, pyroxene.

4. GABBRO. Chief mineral is Pyroxene. Subordinate minerals may be feldspar, hornblende, olivine and mica.

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

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 rhyolites, many of the andesites, most of the trachytes, latites and phonolites.

2. FELSITE-PORPHYRY: 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.

3. BASALT: All dark-colored felsitoid rocks with few or no phenocrysts. The colors may be dark gray, brown, dark green, black.

4. BASALT-PORPHYRY: All dark-colored porphyritic rocks with felsitoid groundmass.

III. Glassy Rocks

Those composed of glass or having a glassy Luster

1. OBSIDIAN: Non-porphyritc, 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.

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.

5. Perlite: Glassy rocks with perlitic structure.

6. Pumice: Highly vesicular rock glass, usually very light-colored.

IV. Tuffs and Breccias (Fragmental)

These may be divided into felsite tuff and felsite breccia (light-colored), and basalt tuff, basalt breccia (dark-colored).

Sedimentary Rocks

In this group are included all rocks derived from pre-existing rocks by processes of weathering or decay, by chemical change, chemical precipitation or life processes. They are grouped as follows:

1. Sand and gravel rocks.
2. Clay rocks.
3. Rocks chiefly of organic origin.
   - *a* Lime rocks, such as limestones.
   - *b* Carbonaceous rocks, such as coals.
   - *c* Siliceous, such as geyserite.
   - *d* Phosphatic—rock phosphate.
4. Chemical precipitates, such as rock salt, gypsum and others.

   1. Sand and gravel rocks include loose sand, gravel, boulders, and the same materials cemented into sandstone, pebble rock, conglomerate. The bonding materials may be lime carbonate, silica or quartz, clay or iron oxides.
   2. Clay rocks include mud, soil, loam, shale, clay shale. Sand, lime carbonate and other substances may be present, and there may be transitions from clay rocks to limestones and sandstones.
   3. Rocks of organic origin include those in the making of which life processes have played a part.

a Limestones are made of lime and carbon dioxide. The lime comes primarily from the igneous rocks and the carbon dioxide from the air or from the interior of the earth. In the weathering of rocks these two unite and form lime carbonate which finds its way to the sea, where it is used by the sea animals to form their shells and other hard parts. At the death of the animals these hard parts accumulate on the sea floor and in time are converted into firm limestone rock. Limestones are rarely pure, but generally contain some clay, silica, iron and magnesia.

b Carbonaceous rocks include coals, asphalts, bitumens, oil shales and oil. The carbon of these is derived mainly from the air by plants and animals.

c Siliceous rocks, such as diatomaceous earth, consist of silica secreted by life agencies.

d Phosphate rock is a phosphorous-bearing rock formed from animal remains, chiefly calcium phosphate.

4. Chemical precipitates, such as rock salt, gypsum and others are precipitated from sea waters in shallow bays and enclosed lagoons by the evaporation of the sea water.

METAMORPHIC ROCKS

The common metamorphic rocks are: Gneiss (pronounced *nice*), schist, slate, quartzite, marble.

GNEISS is a rock in which the component minerals are more or less segregated into irregular alternating layers giving it a streaked appearance. The commoner gneisses are derived from the various granitoid igneous rocks and are called: Granite gneiss, syenite gneiss, monzonite gneiss, and so on. If the rock shows but little of the segregation it may be called a gneissoid granite, gneissoid syenite and so on.

SCHIST is a rock in which a fairly perfect segregation of the component minerals has taken place, causing the rock to have a thinly laminated structure along which it splits easily. The

Limestone strata

Alternation of hard and soft strata (limestone and shale)

Conglomerate
Boulder, Colo.

Banded sandstone

Sandstone
Boulder, Colo.

commoner schists are: Mica schist in which one of the micas is very prominent. The other minerals may include quartz, hornblende, some feldspar. Hornblende schist in which hornblende is abundant. Quartz is the most common other mineral. Schists are formed from both igneous and sedimentary rocks by metamorphism.

Slate is derived from clay rocks by a process of lamination and partial or complete crystallization. The minerals resulting from crystallization may include mica, pyrite, quartz, calcite and others. The softer slates are called clay slates.

Quartzite may be defined as a sandstone which has been so changed by metamorphism that it no longer breaks around the sandgrains but through them. The bonding of the grains is as strong as the grains themselves.

Marble is a metamorphosed limestone. In the change it has become crystallized, commonly whitened, and sometimes mottled. Impure limestones make colored marbles.

TOPOGRAPHY

Colorado is divided into three topographic zones—the eastern plains, rising from an elevation of a little less than 4,000 feet along the eastern border to 6,500 feet at the mountain front; the Rocky Mountain zone, the east side of which rises abruptly from 6,500 feet to the crests of the ranges where many peaks are over 14,000 feet high; and the western plateau zone, extending to the Utah line.

About two-fifths of the state lies in the eastern plains zone, and the remainder is about equally divided between the mountain and plateau zones. The prominent features of the eastern zone are the shallow valleys of the Arkansas and South Platte rivers, and the broad flat divide between them.

The northern boundary of the state in this eastern zone follows closely the flat divide between the North and South Platte rivers. The head waters of the tributaries of the South Platte have cut narrow valleys into the divide.

The divide between the Arkansas and the Cimarron rivers is plateau-like and is cut into deep canyons by the tributaries of the two rivers. At the eastern border of the state the divide is about half way between the Arkansas and the New Mexico line. Farther

Gneissoid granite

Foliated gneiss

Banded gneiss

Biotite schist

Slate

Mottled marble

Onyx marble

west it approaches the New Mexico line and crosses it near the west end of Mesa de Maya.

The Rocky Mountain zone is a complex of ranges. Facing the eastern plains from north to south are: The Front Range extending from beyond the Wyoming line to Pikes Peak, and the Sangre de Cristo from the Arkansas River to the New Mexico line. The Wet Mountains are an isolated range parallel to and east of the Sangre de Cristo, extending from the Arkansas to the Huerfano.

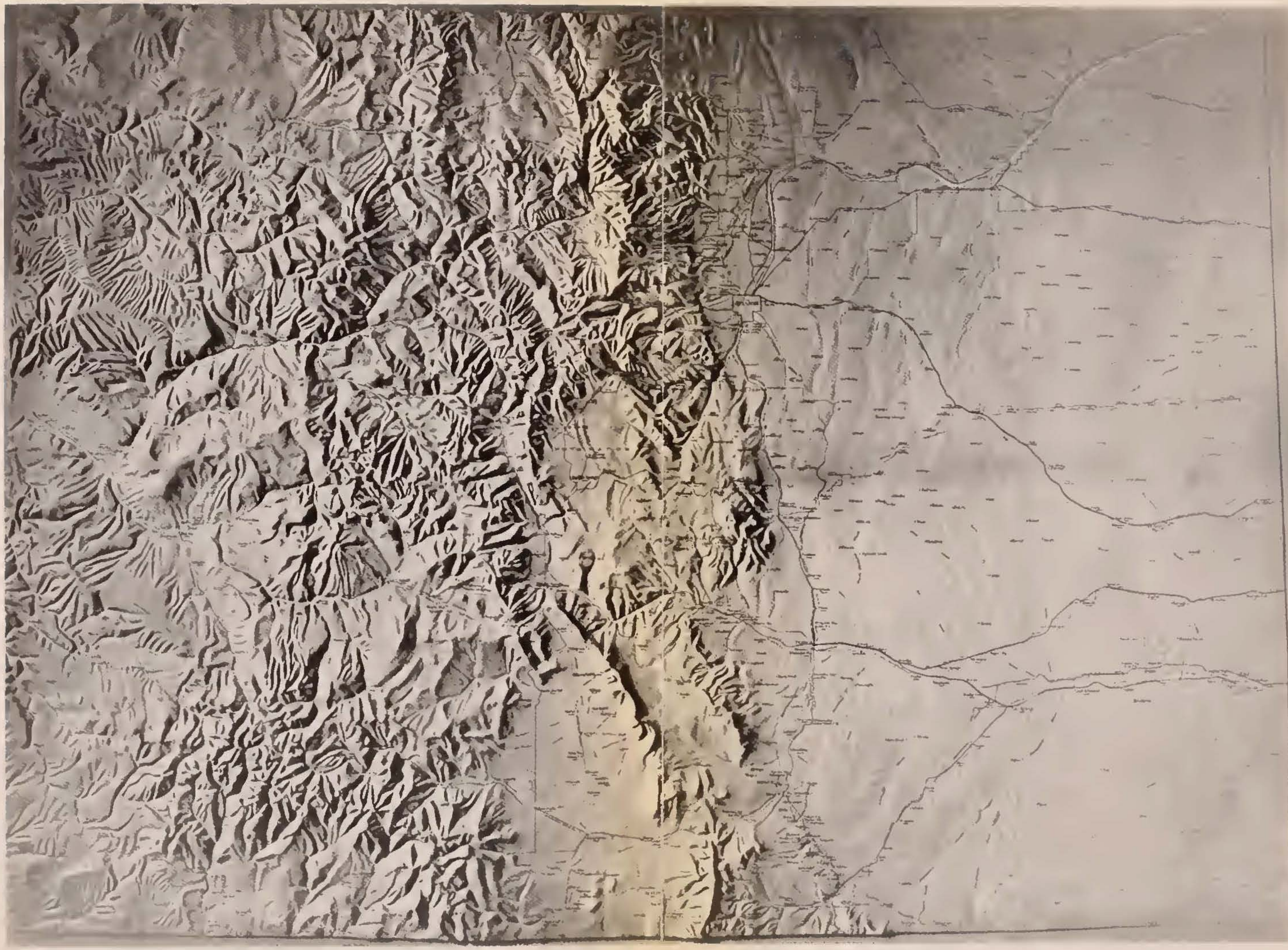
Various local names are given to divisions of the Front Range, such as: Medicine Bow, a northern spur between the Laramie and the North Platte rivers; the Snowy range between Clear Creek and Grand counties; the Rampart Range from South Platte River to Fountain Creek; Tarryall Mountains; Kencsha Hills, and others. The Culebra Range is that part of the Sangre de Cristo immediately north and south of the New Mexico line.

The Park Range extends from the Arkansas River in Fremont County northward through Colorado into Wyoming. Such local names as Mosquito, Gore, and others are applied to parts of the Park Range.

Between the Front Range and the Gore and Park ranges are minor connecting ranges and spurs such as the Rabbit Ears, Vasquez, Williams River and others. The Sawatch range on the west side of the Eagle and Arkansas valleys is one of the most massive in the system. In it are Mount Elbert and Mount Massive, the two highest peaks of the state, the Mount of the Holy Cross, and the Collegiate Group, all over 14,000 feet in height. West of the Park Range lie the Elk Head Mountains in Routt County, and west of the Sawatch are the Elk Mountains in Gunnison County.

The San Juan Mountains are a massive, rugged group in the southwest corner of the state. Many peaks are over 14,000 feet high. The Needle Mountains of the San Juan contain the most precipitous peaks in the state.

Between the Front and Park ranges are the North, Middle and South parks. The North and the South parks are great level expanses ranging in elevation from 8,000 to 10,000 feet. Middle Park consists of a series of minor valleys separated by mountain ranges of considerable height.



RELIEF MODEL OF COLORADO

Between the Sangre de Cristo and the San Juan Mountains lies the great level floor-like San Luis valley at an altitude of 7,000 to 8,000 feet.

The east end of the great Uinta Arch extends into the northwestern corner of Colorado from Utah.

The plateau zone consists of a great series of mesas or plateaus flanking the mountains and declining gradually or by step-like intervals to the western borders of the state. Their surfaces are fairly uniform. Some are horizontal, others are inclined at various angles toward the west, northwest and southwest. The valleys about their borders are usually canyons.

DRAINAGE

The continental divide forms a very irregular line lying mainly between Meridians 106° and 107° west. It parts the waters of the state, sending those of the east slope to the Gulf of Mexico by way of the Mississippi and the Rio Grande, and those of the west slope to the Gulf of California by the Colorado. The principal rivers of the east are: The North Platte, South Platte, Arkansas and Rio Grande, all of which rise in the mountains and pour their waters through deep and rugged channels to the plains, where they are fed very meagerly by the various plains tributaries, most of which are intermittent. As the precipitation in the Rocky Mountain zone is heavy, the volume of water originating in the state is comparatively large.

The rivers of the west slope are: The Colorado and its tributaries: the Bear (Yampa), White, Gunnison, Dolores, and San Juan, all of which head in the mountains, where they receive numerous tributaries, and flow to the more arid plateau country, receiving small contributions from the intermittent streams from the plateaus.

The rainfall ranges from 40 inches per year on some of the divides to 10 inches per year in parts of the western plateau zone. The precipitation is largely confined to the six months from May to October, and, as a consequence, the stream flow is subject to notable seasonal variations.

Within the mountain and plateau zones the canyon is the typical form of valley. On the eastern plains this type is not common except toward the head waters of the streams rising on the divide between the Arkansas and the Cimarron, and to a limited extent on the head waters of the North Platte and South Platte rivers.

Everywhere in Colorado there is an evident relationship between geology and topography. The three topographic zones discussed are related to three geologic zones, and except for certain arbitrary limitations for convenience of discussion, they might be regarded as practically coincident. They are an eastern and a western sedimentary zone, and a central complex zone in which igneous, metamorphic and sedimentary rocks are fairly equally represented.

The eastern sedimentary zone is the great area of sedimentary rocks east of the mountains. The sharply upturned western margins of the sedimentary formations are included in the Rocky Mountain topographic zone since they present a topography more like that of the mountain zone. The boundary between the eastern sedimentary zone and the central mixed zone is an irregular line whose average position is a little west of meridian 105°, through Larimer, Boulder, Jefferson, El Paso, Fremont, Pueblo, Huerfano and Las Animas counties. To the west of this line lies the great complex of metamorphic, sedimentary and igneous rocks whose western boundary from the Wyoming line to the Gunnison River is roughly meridian 107°, 30′. From the Gunnison it sweeps westward to include the San Juan, and then southeast across La Plata and Archuleta counties to the New Mexico line east of meridian 107°. The western sedimentary zone occupies the remainder of the state. In both of the sedimentary zones there are areas of igneous and metamorphic rocks, but the great preponderance of sedimentary rocks at the surface justifies the general classification of these as sedimentary rock zones.

GENERAL DESCRIPTION OF ZONES

Underlying the whole continent is a basement or floor of pre-Cambrian rocks similar in all respects to the pre-Cambrian rocks of the Colorado mountain area—granites, gneissoid granites, schists, quartzites and slates. This statement is based upon the observation that at hundreds of places these rocks are exposed. In short, wherever erosion has cut through the rocks of Paleozoic age this pre-Cambrian complex is found. In Colorado, it is the surface rock in thousands of square miles in the mountain zone, and similar areas occur in New Mexico and Wyoming. There are outcrops in the Uinta mountains; at many places along the Uncompahgre Plateau; in the Needle Mountains; on the White River Plateau, and elsewhere. In many places in the Kansas oil fields wells have been drilled through all the later formations into pre-Cambrian granites, gneisses and schists.

The plane between these ancient rocks and tho overlying formations marks a very abrupt change in geologic conditions, and geologists believe that the pre-Cambrian rocks are very much older than the rocks which rest upon them. These geological differences and the evidences of great difference in age are indicated by the following facts:

Metamorphic and igneous rocks prevail in the pre-Cambrian. In the later formations sedimentary rocks are most abundant. Igneous rocks are locally abundant, but metamorphic rocks are comparatively rare. The older the rocks the more likely they are to be metamorphosed or changed in composition and structure, since they have been longer subject to all those processes which bring about change in the materials of the earth. The older the rocks the more likely are they to become mixed and complex. Molten rocks from within the earth find their way to the surface through volcanic and other vents and mingle with the surface rocks. The older the formation the more likely it is to be cut by and mingled with igneous rocks.

Fossils and other evidences of life are extremely rare in the pre-Cambrian rocks. The few fossils found are of low or primitive forms of life. The overlying rocks are rich in fossils and other evidences of life of a more advanced type. The great gap between the life records of the pre-Cambrian and those of the later formations represents a long period of time during which life developed from fewer and lower forms to the more abundant higher forms of the Paleozoic. The record of this long period of time was certainly written in the rocks of the sea floor whether on the present continental areas or somewhere beneath the oceans.

If the seas in which this life developed covered part of the continent of America we must assume that the rocks containing that record have been removed by erosion, or, that they lie hidden by the later formations. It is a very significant fact that nowhere on the continent of North America has been found a direct uninterrupted succession of rocks from the pre-Cambrian to the Cambrian. The evidence that a long period of land conditions and erosion preceded the Cambrian is most convincing, and geologists believe that the continent had very much the present outline and size. If this is right the life record of this land period was written in areas now, as then, covered by the seas.

So long was this period of land conditions and erosion that the surface of the continent was worn down almost to a plain. There were no mountain ranges, no deep valleys, no swift rivers and no sea cliffs. Wherever this ancient continental surface may be studied it is found to have been gently undulating, and covered with the products of rock decay, which the sluggish rivers could not carry away to the sea.

At the present time this ancient surface stands at various heights above the sea. In the eastern part of the state it is covered by thousands—at least 3,000 to 4,000 feet, of sedimentary rocks and must be as low as sea level. In the mountain zone the highest peaks are topped by pre-Cambrian rocks at 14,000 feet above sea level. On the western borders of the state the pre-Cambrian floor is also near sea level. These great differences of level of this old continental surface are due to Paleozoic, Mesozoic and Cenozoic movements of elevation, upward folding and faulting.

Regular stratification or bedding is comparatively rare in the pre-Cambrian rocks. It is the rule in the overlying formations. Earth movements, volcanic activity, the work of the atmosphere and of water all tend to destroy the original layers or strata in which sedimentary rocks are laid down.

The older the rocks the less do they retain of their original forms, compositions and structures. The pre-Cambrian rocks are notably changed in these respects.

Slaty, schistose and gneissoid structures are very common in the pre-Cambrian rocks, but comparatively rare in later formations. These structures are the result of pressure, movement and changes of mineral composition and arrangement. The older the rocks the more have they been subjected to these processes of change.

Coal, oil, natural gas and other bitumens are almost unknown in the pre-Cambrian rocks. They occur in rocks of every later age, and in some abundantly.

But there can be little doubt that plant life was abundant before the Cambrian. The Grenville series of pre-Cambrian rocks of Eastern Canada contains carbon in amount comparable to that of the great coal beds of the Carboniferous. Anthracite coal of good quality is mined in the pre-Cambrian rocks of Finland, and graphite is abundant in pre-Cambrian rocks in many parts of the world. It is not unreasonable to hold that the carbon of these very ancient rocks came from plant life.

Oil and natural gas are formed from plant and animal remains. They are easily destroyed and they readily escape from the containing rock. Their absence from pre-Cambrian rock is not proof that vegetation sufficient to produce oil and gas did not exist in pre-Cambrian time. In a few places veins of hydrocarbons probably derived from petroleum are found in the pre-Cambrian rocks.

A picture of the Colorado area of late pre-Cambrian time would be somewhat as follows: The surface would be low and undulating, the valleys broad, the rivers sluggish—carrying only the lightest sediment such as mud and sand. The rocks would be deeply weathered and decayed rock would rest on the surfaces where it formed. The outcrops of more solid rock would be comparatively few and would be much jointed and the blocks rounded into boulders of decay. Some of our higher and flatter valleys of the mountain area present a picture quite similar to the landscape of the Colorado area in pre-Cambrian times. But there would be practically no limestone, no shale, no sandstone. Schists, gneisses, granites, would prevail, but here and there, as along Coal Creek, the Big Thompson, near Salida, along the Uinta area quartzites derived from sandstones and schists formed from shales or clay rocks would relieve the monotony of the landscape.

No grasses, trees or shrubs would clothe the land, and land animals would be absent. It is probable that along the streams, and in lakes and shore waters herbaceous vegetation was fairly abundant before the close of the pre-Cambrian, but probably only in the seas would there be much evidence of animal life.

Chapter 2

GEOLOGIC ERAS

ARCHEOZOIC, PROTEROZOIC (PRE-CAMBRIAN) AND PALEOZOIC

PRE-CAMBRIAN ERAS

In a general way the term pre-Cambrian includes all geologic time before the opening of the Paleozoic era. But as we know geologic history chiefly through the rocks exposed at the surface of the earth, the term, as commonly understood, stands for that period of the earth's history represented by outcropping rock formations which are older than the Cambrian. It is commonly divided into two great eras; the Archeozoic and the Proterozoic. The formations of the Proterozoic are commonly called Algonkian. Those of the Archeozoic era are called the Archean system or the Archean complex.

In the region of the Great Lakes the history of the pre-Cambrian is somewhat readily divisible into the two eras, and the Proterozoic, at least, is divisible into periods. But in the Rocky Mountain region very few areas have given clear evidence of a natural division of the pre-Cambrian into eras, and no satisfactory subdivisions of the eras into periods has yet been made.

For these reasons many large areas on the geological map of Colorado are called simply pre-Cambrian, and no attempt has been made to subdivide them into Archean and Algonkian. In a few regions such as the San Juan, more detailed investigation has made it doubtfully possible to separate the Archean and Algonkian areas. As a general rule, in the San Juan, geologists have mapped as Archean those pre-Cambrian rocks which have been so profoundly metamorphosed by compression, folding and mashing, that their original character has been completely destroyed. They are schists and gneisses, and what little evidence of their origin can be found points to a development from igneous rocks. The Algonkian contains some greatly altered rocks of igneous origin and some derived from sediments. In the first of these belongs the Irving greenstone; to the second, the Needle Mountains group.

The Irving formation consists of a complex series of schists, greenstones and a small amount of quartzite, having a probable thickness of 10,000 feet. The most important member of the series is unstratified igneous rock into which other igneous rocks have been intruded. All are profoundly altered by metamorphism, and in many places the original structure has been completely destroyed.

The Needle Mountains group includes the Vallecito conglomerate and the Uncompahgre formation. The Vallecito conglomerate overlies the Irving, from which it is separated by an unconformity. It is a coarse conglomerate made up of pebbles and boulders of greenstone, quartzite and some jasper and magnetite. In places it is schistose, and locally quartzite conglomerate and quartzite occur.

The Uncompahgre formation consists of a basal quartzite 1,500 feet thick, followed upward by great series of alternating quartzites, and slates or shales making a total thickness of about 5,000 feet.

The mapping of most of the pre-Cambrian geology of the state is very general and incomplete. Many areas containing distinct formations have not been divided in mapping. In others, the volume of intruded rocks, ranging in age from pre-Cambrian to Tertiary, far exceeds that of the regular pre-Cambrian formations. In many places the formations commonly regarded as Algonkian rest upon these eruptive rocks which may be of much later age. In some places, as on the slope of Arapahoe Peaks, we find typical quartzites interbedded and conforming in dip and strike with very ancient looking schists and gneisses which would ordinarily be called Archean.

A comparison of the recent map of the Georgetown area with that of the area surrounding it will show that we know very little of the detailed geology of the pre-Cambrian of Colorado. In this area it was found impossible to divide the pre-Cambrian formations into Archean and Algonkian. The oldest rocks of the quadrangle (the Idaho Springs formation), are believed to be of sedimentary origin, and vastly older than the quartzites of South Boulder Canyon, which have been classed by some geologists as Algonkian, but which may be as late as Mississippian. Rocks of sedimentary origin occur elswhere in the Archean, and it is more than probable that they occur in the Archean of Colorado.

THE ARCHEOZOIC ERA

The Archeozoic era was extremely long, possibly as long as all other geologic eras combined, and the relations of land and sea must have changed many times. It is probable that the area of Colorado was many times below the sea and many times occupied by dry land during the era. Wherever the rivers have cut their valleys down through the later rocks Archean schists and gneisses have been exposed, and there is little reason to doubt that these rocks underlie the entire continental area and form the foundation or platform upon which the later rock systems rest. Toward the close of the era a group of islands separated by broad channels and shallow seas occupied a part of the area of the present state of Colorado, and extended northward and southward into Wyoming and New Mexico. The easternmost of the islands seems to have been several hundred miles long, and very irregular in outline. Its position was roughly that of the great eastern pre-Cambrian area shown on the geologic map. Another island lay where the Needle Mountains now stand, and a third stretched from the northwestern corner of the state far into Utah along the line of the Uinta Mountains.

The rocks of these island areas, as we find them today, consist of schists, gneisses, gneissoid granite, granite and other igneous rocks. The less altered rocks are in large part, if not all, later intrusions, and did not form a part of the Archeozoic islands. As these ancient island rocks have undergone many upheavals, tiltings, foldings and squeezings, it is safe to assume that they have been greatly altered since they stood above the Archeozoic seas. But that some of them were even then very much like the Archean rocks of today is shown by the fact that igneous rocks intruded into the Archean formations in early Cambrian or pre-Cambrian times contain blocks of schist and gneiss torn from Archean formations through which they passed.

Before the close of Archeozoic time the surfaces of the islands had been cut down by erosion until they stood at no great height above the sea level, and were comparatively even.

Archeozoic Life

Limestone (now largely changed to marble), was probably formed as in later geologic ages, from accumulations of the lime carbonate of shells and other hard parts of invertebrate animals. Limestone is very abundant in some Archeozoic formations, but in Colorado it is rare. A few bodies of lime silicate rock, possibly formed from limestones by metamorphism are found in the pre-Cambrian areas, but whether they are Archean or Algonkian is still uncertain.

Graphite (carbon) is abundant in some Archeozic rocks and was probably derived from plant and animal remains, as in later geologic times.

Iron Ores. Certain iron ore deposits are now being made by the aid of life forms—mainly plant—and there is good reason to believe that the iron ore of the Archeozoic rocks may have had a similar origin in part at least. Forms believed by some geologists to be fossil algae are found in the iron-bearing rocks of Archeozoic age in the Vermilion Iron Range of Minnesota. The fact that the fossils found in Proterozoic rocks represent an advanced evolutionary development makes it probable that animal life started in the Archezoic long before the beginning of Proterozoic time.

THE PROTEROZOIC ERA, OR ALGONKIAN TIME

At the opening of Proterozoic or Algonkian time the relations of land and sea were much the same as those of late Archeozoic time. Just how large the Algonkian land areas were it is impossible to determine, and they seem to have been mainly in what is now the mountain zone of the state.

From these Algonkian land areas the rivers carried to the Algonkian seas the sediments and spread them over the sea floor in layers or strata of conglomerate, sandstone and shale. The outcrops of known Algonkian rocks in Colorado are not large, but it is very likely that extensive areas lie buried beneath Paleozoic and later formations.

The principal Algonkian formations to which special names have been given are the Irving greenstone and the Needle Mountains group in the San Juan, and the Uinta formation in the Uinta Mountains. On Coal, South Boulder, Big and Little Thompson, and Buckhorn creeks in the eastern foothills of the main range are considerable areas of quartzites, quartz-mica schists and mica schists which may be Algonkian. Near Salida is a thick series of rocks very similar to the Irving greenstone, and probably of the same age.

The Irving greenstone consists of massive, gneissoid and schistose basic igneous rocks, commonly called greenstones, together with a small amount of quartzite. In the Uinta formation shales and red sandstones are abundant, but the bulk of the rock is quartzite. The Needle Mountains group consists of a conglomerate (the Vallecito) at the base, followed by a series of shales, and quartzites (the Uncompahgre).

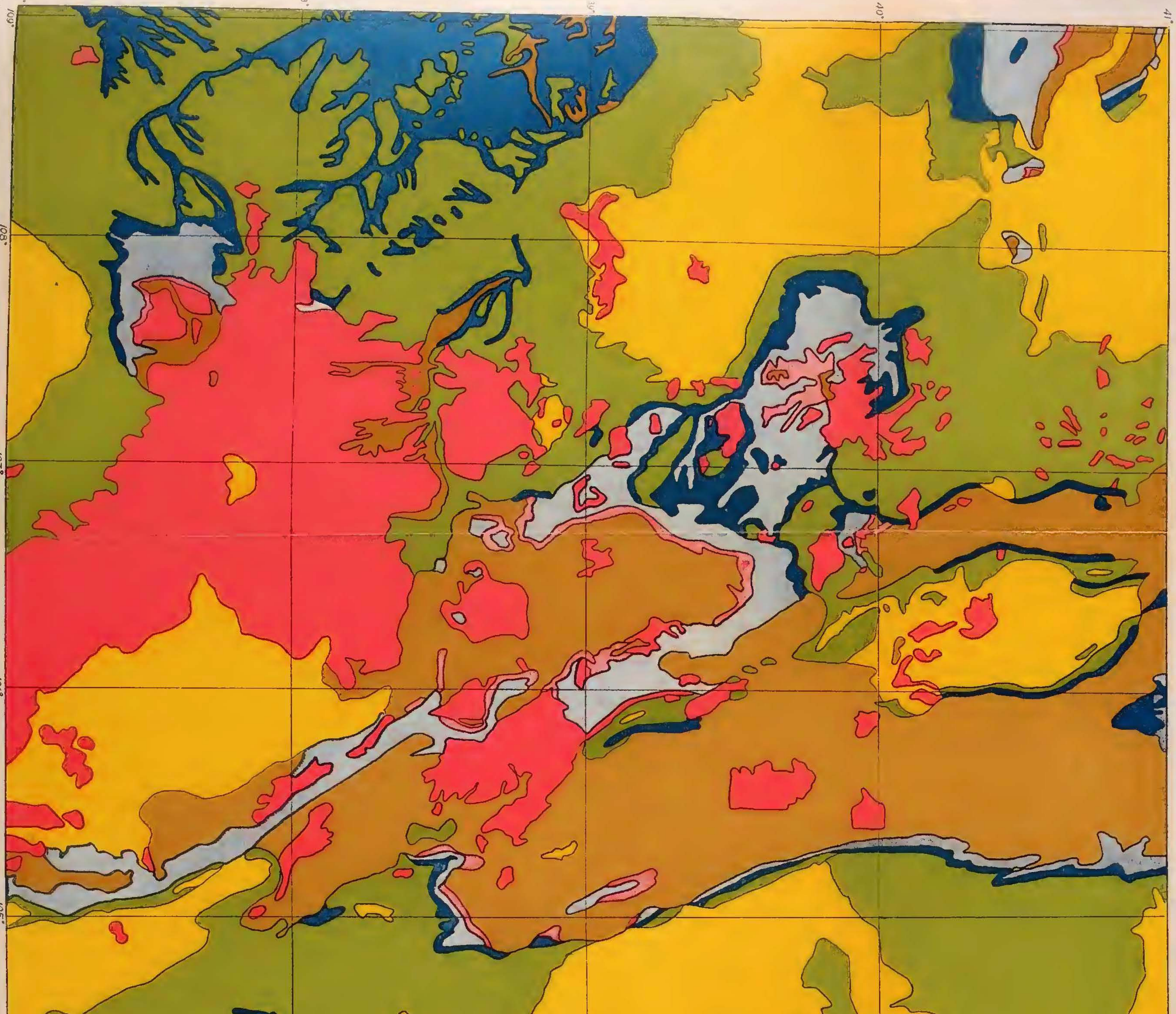
The Uinta formation varies in character from place to place. Locally it consists almost entirely of compact, dense quartzites. In other places there are all gradations from conglomerate and quartzite to a soft sandstone. The prevailing color is reddish brown, but purple is common about the middle, and white strata are found in some places. The formation is over 10,000 feet thick, and the strata dip steeply to the north.

In many places in Colorado vast volumes of intruded and extruded igneous rocks are so related to the pre-Cambrian formations as to suggest tremendous volcanic activity in the Proterozoic era, and especially near its close. The great granite bodies of the Needle Mountains and adjacent areas are probably of late Algonkian age, and there is some reason to believe that those of the Pikes Peak area are also Algonkian. Long before the Proterozoic era closed, crustal movements greatly increased the land areas in the Rocky Mountain region, and drove the seas back, beyond the borders of the state and probably entirely off the continent. The Algonkian rocks underwent so much folding, compression and kneading that they were, in places, completely metamorphosed before they were covered by the Upper Cambrian rocks which were the next sedimentary formations laid down within the borders of the state. The clay rocks were largely changed to schists, the sandstones to quartzites and the sandy clays to quartz-mica schists. The basic igneous rocks of the Irving greenstone formation were in part changed to schists and gneisses.

PROTEROZOIC LIFE

It is reasonable to hold that a large part of the limestones, carbonaceous shales and slates, and iron ores of the Proterozoic was formed, as in later geologic times, by the help of life processes.

GEOLOGIC MAP OF COLORADO



Very heavy limestone reefs and ledges in the Proterozoic rocks of Montana were formed by lime-secreting algae.

To the more obscure evidences of life may be added the convincing testimony of many identifiable fossils. Of the animal kingdom, at least six of the nine grand divisions are represented by identifiable fossils, and it is highly probable that all but the vertebrates had appeared before the end of the Proterozoic.

The Protozoa are represented by radiolaria and probably foraminifera. Several orders of siliceous sponges are found fossil. Highly organized worms lived. Bryozoans (moss-like animals) and probably brachiopods have been found fossil. Clam-like shellfish (pelecypods) represent the Mollusca. Crustaceans resembling huge lobsters occur in the Proterozoic of Montana.

Plant life was abundantly represented by algae.

Several facts help to account for the scarcity of fossils in the Proterozoic rocks of America. Life was probably not very abundant. The Proterozoic rocks are, as a rule, highly metamorphosed, and this tends to obliterate evidences of life. Most geologists believe that in America the Proterozoic was a time of continental sedimentation, and this is unfavorable for abundant life, and for the preservation of life remains. To these may be added the fact that in the very long period of erosion which preceded the opening of Cambrian time all the later Proterozoic rocks would be disintegrated and removed. But there existed great seas in which flourished and evolved the abundant life with which the Paleozoic era opened.

PALEOZOIC ERA

CAMBRIAN PERIOD

Somewhere under the vast areas of later rocks on the continent of North America there may be sedimentary rocks proving that there was no time break between Proterozoic or pre-Cambrian and Cambrian. But no such place has yet been found, and all the evidence both of rocks and of fossils tells us that for a very long time before the making of the first Cambrian rocks the continent had been a land area subject to weathering and erosion, and had been reduced to a comparatively uniform surface at no great height above sea level.

Early in Cambrian time the seas invaded the continental borders and advanced slowly toward the interior, but did not reach Colorado until nearly the close of the period, and as a consequence no Lower, Middle or early Upper Cambrian rocks are found in the state. The first invasion of Colorado by the Cambrian seas was from the northwest.

The waters of the advancing sea found the surface covered with decayed rock. As a very large part of the surface was granite the covering of broken rock, sand and clay was like that now lying on the granite areas in the mountains today, and from the surface downward there was a gradual change from the completely decayed, clayey mantle rock to the fresh unaltered bedrock below. This transition is observed in many places where the streams have cut through the Cambrian formations to the pre-Cambrian, as in the Leadville and Aspen areas.

The rivers which formerly carried the sediments to the oceans bordering the continent now dropped them in the shore waters of the invading seas. The waves of the advancing sea took the residual surface material and the sediments brought in by the streams, assorted them and spread them over the sea floor in layers or strata of conglomerate, sandstone and shale. In some parts of the sea the shore waters were clear and made a favorable habitat for animals and plants. The animals took lime from the waters, made it into their shells and other parts, and as the animals died these accumulated on the bottom. Century after century these accumulations grew, and the waves broke and ground many of them into a mud-like mass and spread a mixture of limestone-mud, shells and shell fragments over the sea floor in layers which afterward consolidated into the limestone strata of the upper part of the Cambrian formation.

Some plants, particularly certain algae, also separate lime from sea water and build limestone strata and reefs, and it is probable that they did their part in making the limestone, just as they did in Proterozoic and later times.

The Cambrian rocks of Colorado include conglomerates, sandstones, shale and limestone. In many places the sandstones have been changed to quartzite. Granitic sandstone or arkose made directly from the disintegrated granite and left almost where the material was found, is common at the base of the formation. Cambrian strata occur at many points along the mountain fronts, along the borders of the pre-Cambrian areas, in the San Juan, along the White River Plateau and in the Uinta Mountain area. They are rarely thick, but in the Ladore Caynon of the Uinta area they reach a thickness of 1,200 feet.

The Sawatch Quartzite is the name applied to the Cambrian in the Sawatch Range and at many other points along the pre-Cambrian borders. It consists of pebbly quartzite or conglomerate at the base, quartzite, sometimes alternating with shales in the middle, and, clayey shales, limy shales and some limestone at the top.

The Ignacio Quartzite of the southwest is largely quartzite but in places contains some shale and limestone. The prevailing color is white to gray, but pink, red and yellow stains are common.

The Lodore of the Uinta region consists of fine to coarse sandstone and conglomerate beds in the upper part, underlain by fine, shaly and sandy strata. The colors vary from white to red, and green mottlings are common. The formation has a maximum thickness of 1,200 feet.

At numerous points along the eastern slopes of the Front Range in southern Colorado the Cambrian rocks consist of sandstones with some shale and a little limestone.

CAMBRIAN LIFE

The fauna was rather scanty but almost all the grand divisions of the invertebrates were represented and some of them had made very notable progress, showing that the previous history of animal life on earth had been very long.

Trilobites and brachiopods were by far the most important types, but sponges, worms, jelly-fish, graptolites, and stromatopora have been found fossil. It is doubtful whether corals had appeared. Fish scales have recently been found in Cambrian strata. Mollusks were fairly abundant, and were represented by clam-like forms, snail-like forms, gastropods, and possibly by forms somewhat like the squid or cuttle fish.

Certain impressions on the bedding planes of strata are believed by some geologists to be those of sea weeds, but many impressions once thought to be made by plants are now known to be worm tracks, A plant-like form, Oldhamia, consisting of a stem bearing clusters of radiating needles resembling pine leaves, is found abundantly in the Cambrian of Ireland. There can be no doubt that plant life was abundant in Cambrian times, but as plants decay readily, and are easily destroyed, it is not surprising that plant fossils are not abundant in the older rocks. In Colorado only late Cambrian rocks are known and fossils are very scarce.

ORDOVICIAN PERIOD

For some time after the opening of Ordovician time the land areas continued to decrease and the seas to advance. Weathering was still preparing the surface rock for the rivers, and they continued to lower the land by carrying the decayed rock material to the sea. But much of the land surface had been worn down to such an extent that the slope to the sea was gentle and the rivers were able to carry but little coarse material. Sand was still reaching the sea along some parts of the island shores. In others the rivers brought down only mud. But in many places the shore waters were clear, marine life was rather abundant, and limestone building was in progress.

It is evident from what has been said that the rockbuilding of the Cambrian period was continued without interruption into the Ordovician period. The materials were still derived from pre-Cambrian rocks for the Cambrian rocks were sinking farther and farther below the surface of the sea and were being covered by Ordovician sediments.

The Ordovician of the slopes of the Front Range is divided into the Manitou limestone, the Harding sandstone and the Fremont limestone. The Manitou follows the Cambrian without break, but after the Manitou was deposited there was an elevation of the sea floor which drained off the waters and brought the Manitou above sea level, exposing it to erosion. In places most of the Manitou was worn away before the sea again covered the area and the Harding sandstone was laid down. Such a relationship is known as an unconformity.

But before the close of the period a notable change took place. The land began to rise and the sea was pushed back until the shore limes lay outside the present outcrops of Ordovician, and possibly far beyound the borders of the state. As a result no Silurian seas are known to have existed within the area of the state, and no Silurian rocks are found in Colorado.

The Ordovician rocks followed the Cambrian, in most places without any break in deposition. But as the seas were still advancing, the Ordovician rocks in many places overlap the Cambrian and rest upon the Algonkian and Archean. As a consequence some sections show the basal Ordovician resting on the Cambrian, as at Manitou. In others owing to the later arrival of the sea the basal Ordovician is wanting and the lowest Ordovician present rests upon pre-Cambrian rocks, as at Canon City.

The earliest Ordovician rocks, where present, are usually dolomites and limestones of varying purity, as at Manitou and Leadville. Above these the strata vary widely from place to place. While limestones were being deposited in one area, sandstones and shales were laid down in others. But, as a rule, shale is not an important rock in the Ordovician series. The limestones and dolomites are followed by an alternation of sandstones and limestones with occasional bands and strata of shales.

The Ordovician formations have almost the same distribution in Colorado as the Cambrian, and are found on the borders of the pre-Cambrian areas, and no doubt underlie large areas of later formations.

Though there are many outcrops of Ordovician rocks the formations are named at only a few places, as follows: Manitou limestone, Harding sandstone and Fremont limestone, along the eastern foothills of the Front Range; the White limestone and Parting quartzite at Leadville, Aspen and many neighboring points; the Yule limestone in Gunnison County; the Ogden quartzite in the Uinta Mountains.

The names of the formations suggest their character in all these instances, and descriptions are unnecessary. The Harding sandstone of Canon City and an equivalent formation in Gunnison County contain fish remains, of primitive fish which were for a long time the oldest known evidences of fish. But recently somewhat similar fossils have been reported from the Cambrian.

The Yule limestone on Yule Creek has been metamorphosed into a large deposit of beautiful marble. The White limestone is related to some of the Leadville ore deposits, and other Ordovician strata are also ore-bearing, but the deposition of the ore occurred long after Ordovician time.

ORDOVICIAN LIFE

The Ordovician was an extremely long period and evolutionary progress was very great. At the end of the Ordovician all the great divisions of the marine invertebrates and most of their important subdivisions had appeared. Migration had brought into American seas types far in advance of the latest Cambrian forms yet found. This seems to prove that great development had taken place in some region not yet known.

The graptolites, the straight shelled cephalopods, the trilobites and some of the echinoderms reached their time of greatest development and began to decline. Important groups include the sponges, pelecypods, crinoids, trilobites, brachiods and corals. Primitive fishes, the ostracoderms (shell-skin) lived in the seas of Colorado and Wyoming. Fossils have been found at Canon City and near Gunnison. They were probably the direct descendants of the types whose scales have recently been found in the Cambrian.

Land plants were probably well developed, but since the known Ordovician rocks are mainly marine, no records have been found. Sea weeds and algae resembling corals in form are found fossil in the American Ordovician strata. Cryptograms are reported from Europe. These were spore-bearing plants such as ferns, mosses, fungi, algae and liverworts.

SILURIAN PERIOD

The seas retreated from what is now the mountain region in late Ordovician time, and there is no evidence of a return to the Colorado area until late in Devonian time. Colorado and much surrounding territory was a land area during late Ordovician, all of Silurian and the greater part of Devonian times. The same inorganic agencies of change were at work upon the rocks as are now breaking down the rocks and preparing them for removal to the ocean basins. The rivers did their work as now—carving valleys, carrying landwaste to the sea and draining the land surface.

But there was a notable difference in the appearance of the region. There were no great mountain ranges, deep valleys or canyons. It is likely that land plants occupied the low lands along the rivers and shores, but vegetation was by no means general. Forest trees or large woody plants had not yet evolved. Animal life on the land was very scarce. The first insects are believed to have appeared in late Ordovician.

Silurian Life

The history of life in the Silurian followed the lines already established in the Ordovician. Some forms reached their highest development and began to decline. Others continued to advance and new types appeared. Considered in the large, there was decided progress, but the period was much shorter than the Ordovician, the continental seas were very limited, and at times only the bordering seas remained to supply favorable life conditions.

Sponges were still abundant, corals and crinoids made great progress, but trilobites declined. The brachiopods were the dominant form of life in the seas. Eurypterids increased in size and numbers but did not reach their greatest development in either respect. Though the brachiopods more than held their own, it was largely by the rapid appearance of new forms, for many Ordovician species disappeared. The fishes were smaller but they made considerable progress in development toward the Devonian forms, of which they were the ancestors. Sharks of primitive type appeared.

Little can be said of the development of plant life. A few doubtful impressions have been found, and a few fern fossils occur in the Silurian of France.

DEVONIAN PERIOD

No early Devonian rocks have been found in Colorado, and therefore we have no direct evidence that any part of the state was covered by the sea during early Devonian time. Just when this period of growth of the Rocky Mountain land area ceased and the seas began again to invade the land, we do not know. But it was not until past middle Devonian time that the sea advancing from the west reached the line which marks the western border of the Front Range. How far the sea advanced from the east in Devonian time we have no means of determining for there is no outcrop of Devonian rocks east of the mountains. But we do know that soon after the close of Devonian time the sea entered certain bays along what is now the eastern base of the mountains.

In Colorado, therefore, we have only late or upper Devonian rocks, and these only west of the Front Range. If, as some geologists believe, the Parting Quartzite is Devonian, the oldest Devonian rocks exposed in Colorado were laid down as sandstones on the floor of the Devonian sea. This formation or its equivalent, seems to be rather widespread in the central zone of the state. But the majority of geologists think it is Ordovician.

The Devonian seas appear to have entered Colorado from the southwest and advanced across the San Juan region toward the north and northeast. Devonian strata occur in the San Juan, at Salida, at Glenwood Springs, along the White River Plateau and elsewhere.

The Elbert formation consists largely of limestones alternating with thin bands of calcareous shales, clay shales and sandstones. In a few places the shales almost equal the limestone in volume, but sandstones are rarely or never abundant. Resting conformably upon the Elbert is the Ouray formation consisting of limestones, with shaly partings and some shaly and sandy layers. The lower two-thirds of the Ouray is upper Devonian, but the upper one-third is of Mississippian age.

The Elbert contains an abundance of invertebrate fossils, and a few fish remains somewhat similar to those of the Ordovician near Canon City. The equivalent of the Elbert is not widely distributed, and it would appear that the Elbert sea did not extend much beyond the San Juan, whereas the later, or Ouray phase, reached the White River area and possibly farther. So far as yet discovered the Ouray sea did not reach Leadville until after the close of the Devonian, and the Leadville or Ouray of Leadville contains only the Mississippian fauna.

The strata of the Ouray formation are apparently conformable throughout, yet the basal part of the formation contains an Upper Devonian fauna and the upper part an entirely distinct lower Mississippian fauna. Between the two faunas are strata without fossils, and in certain localities there is a rather abrupt change in the character of the sediments, but this change is in the barren beds between the two faunas. This may mark the dividing plane between the Devonian part of the formation and the Mississippian, but there is no other evidence of a disconformity or a break in sedimentation. There is, however, a complete break in the life history as recorded in the Ouray formation. The two faunas are absolutely distinct. Not a single Devonian species lived on into the Mississippian in the Colorado area.

We may attempt to account for this by assuming that the Devonian fauna migrated from the area and left the late Devonian waters uninhabited; or that the Devonian fauna died out; or that the sea floor rose and the area became land. But land conditions could have existed only a short time for there is little or no evidence of erosion. The Devonian part of the Ouray consists of limestones with thin separating shales or marls. In some places the limestone is sandy.

Devonian Life

The Devonian marks a very great forward stride in several lines of life development, but the progress was not general.

The trilobites, the rulers of the Cambrian seas, were but a very subordinate feature of Devonian marine life. They tried to make up for their deficiency in numbers by the development of fantastic forms and rich ornamentation. The brachiopods reached their climax. Corals were extremely abundant, and built many reefs. The abundance, size and variety of fishes justify the name "Age of fishes" for the Devonian. Over 100 species and more than 40 genera of fresh water fishes are known. Marine forms were only less numerous than their land-water relatives. Amphibians were probably present, but as yet little fossil evidence has been found.

A varied, rich and luxuriant vegetation existed, and fossils of all the higher cryptogams are found. Many of them were represented by large tree-like forms, and the first forests appear. Ferns, clubmosses and horsetails were represented by very large species such as the lepidodendrids, which reached tree proportions. Logs of primitive evergreens are found fossil in late Devonian strata. These plants were probably more like seed-bearing ferns than like the conifers of today. The connecting links between the flowering and non-flowering plants, known as the cycadofilices —(cycad-ferns), appeared in the Devonian.

Primitive flowering plants having unisexual flowers without perianth or true flower leaves are found fossil. The Devonian flora was the direct ancestor of the still more abundant flora of the Pennsylvanian.

MISSISSIPPIAN PERIOD

The break in the life story as recorded in the Ouray formation is best interpreted by assuming that there was a rather sudden retreat of the sea in late Devonian time, followed by an equally sudden return in early Mississippian time. The land period between the two was so short that no evidence of erosion between the strata of the two periods has been found.

This return of the sea marks the beginning of a very widespread subsidence of the land, and it is probable that almost the entire area of the state was covered by the early Mississippian seas. Early Mississippian strata are much more widespread than the Devonian. The land was slowly sinking and the seas advanced upon the land. The rivers brought in the products of land waste and the waves spread them over the sea floor covering the Devonian strata and overlapping onto whatever formations made up the subsiding land surface. As a result, we find Mississippian rocks resting upon Devonian, Ordovician, Cambrian and pre-Cambrian. This was the most complete submergence of the Colorado area since pre-Cambrian time. How long this subsidence of the land and advance of the seas continued we do not know, but the evidence suggests that crustal warping began at the close of Madison time and opened a period of elevation or upheaval, in which the shallow bordering sea waters were drained off to the deeper sea basins and the eastern shore line of the great western sea was pushed back, possibly to or beyond the western border of the state. To the south, in New Mexico the Mississippian sea became the Pennsylvanian sea, and Mississippian strata are followed without break by Pennsylvanian strata.

Only the lower part of the Mississippian is present in Colorado. The formation has received several local names. In the San Juan and elsewhere the name Ouray is in common use, but only the upper part of the Ouray is of Mississippian age. In several mining districts, such as Leadville, Ten Mile, Aspen, Crested Butte, Alma, Red Cliff, Monarch and Tomichi and Gold Brick, it is called the Leadville or Blue limestone or occasionally the Ouray. It is known in the valleys of the Eagle, the Grand, the

Dolores and the White rivers, and in the Sangre de Cristo, the Uinta, the Elk and the Front Ranges. East of the Front Range it is called the Millsap. It is called the Wasatch in the Uinta and Wasatch ranges.

The equivalent formation is widespread in Wyoming, Montana and elsewhere in the north and is known as the Madison. As this is the most widely and consistently used name it should be adopted for general use, though it can never displace the local names.

The Mississippian part of the Ouray at Ouray consists of 70 feet of light bluish-gray to nearly white limestone. The Leadville or Blue at Leadville is a deep grayish-blue heavily bedded series of dolomitic limestones, in the upper part often coarsely crystalline, having an average thickness of 200 feet. This description applies to the formation in many places. The Millsap is mainly limestone, but its color varies from gray to purple, buff, red and brown, owing to different conditions of deposition and subsequent history.

In northwestern Colorado the Madison consists of gray cherty limestone with a little gray sandstone near the base, and reddish sandy material at the base. It rests unconformably on older formations which may include pre-Cambrian. It is not exposed along the foothills in northeastern Colorado, but in the basal part of the Fountain typical Mississippian fossils and blocks of chert containing Mississippian fossils from parts of a pebbly conglomerate.

In the San Juan the Molas formation of Pennsylvanian age contains many chert blocks carrying Mississippian fossils like those of the Ouray, on which the Molas rests, but the Matrix of red marl or calcareous mud is clearly of Pennsylvanian age.

In the western part of the continent there began in late Mississippian time a series of geological and climatic changes which gradually extended over the whole of North America. They reached a climax in the major upheaval known as the Appalachian Revolution, which, in Permian time, built the Appalachian Mountains where, during the greater part of the Paleozoic Era, a sea trough with a sinking floor had received thousands of feet of sediments carried by the rivers from the bordering highlands.

Crustal movements converted dry land into shallow sea basins or salt lakes, or caused the epicontinental seas to return their waters to the ocean basins, leaving broad flat expanses over which meandering rivers spread sediments from the higher lands. The climate became arid in the Rocky Mountain region in Mississippian time and remained arid almost continuously until the end of the Triassic. As time went on the aridity extended eastward, and prevailed over the continent in the Triassic period.

MISSISSIPPIAN LIFE

The Mississippian life is, in many respects, an orderly continuation of the life movements of Devonian time. The trilobites were represented by a few highly ornamented genera. The crinoids reached a wonderful climax both in numbers and beauty rather early in Mississippian time, and in a small area near Burlington, Iowa, 400 fossil species have been found in the Burlington limestone, which is composed very largely of fragments of crinoids. They declined greatly even before the close of Mississippian time.

Reef-building corals seem to have deserted the American seas, in spite of what appear to have been favorable conditions. Neither crinoids nor corals were abundant in the western Mississippian faunas. Brachiopods and bryozoans were abundant in all the Mississippian seas. The nautiloid cephalopods were gradually giving place to the ammonoid type. Fresh-water fishes had reached their greatest development and had notably declined, but marine fishes and especially the sharks advanced to easy supremacy. Over 400 species of Mississippian sharks are known, and the shell-feeding, pavement toothed forms were dominant. Amphibians, the first air-breathing vertebrates were fairly numerous in Europe, but less so in America. They became very numerous in Pennsylvanian time.

The Mississippian land plants were intermediate between those of the Devonian and those of the Pennsylvanian.

PENNSYLVANIAN PERIOD

Long before the end of Mississippian time a general rise of the Colorado area began and the seas were drained back beyond the border of the state (except possibly in the Uinta Mountain section), and Colorado became an island or peninsula, for marine conditions continued both to the north and to the south.

Weathering disintegrated the rock surfaces and prepared materials for the streams to carry to the sea. Before the return of the seas at the opening of Pennsylvanian time, what had been the Mississippian sea floor—a monotonously uniform plain—was carved into hills and valleys, and presented a topography much like that of the eastern plains of the state, at the present time.

Then followed a period of subsidence. The seas slowly crept over the land, and the waves assorted the materials they found on the surface, carrying the finer sands and clays into deeper water to make sandstone and shale, and leaving the coarse as a conglomerate to form a base for the new strata to be built out of the sediments carried in from the land by the rivers. These new conditions mark the opening of the Pennsylvanian period. In many places the Pennsylvanian strata covered the edges of all earlier Paleozoic rocks and extended out upon the pre-Cambrian formations. In fact, there is such a wide distribution of Pennsylvanian rocks that very little of the state could have stood above sea level.

In the western part of the state the Pennsylvanian opened as a truly marine period, and locally it continued so to the end. In other places the true marine conditions lasted but a short time and were succeeded by continental conditions under which the sediments were deposited in continental basins often wholly cut off from the sea, and along river courses and flood plains and in fresh water basins rarely of long life.

The continental deposits are characterized by great irregularity of bedding, the prevalence of cross-bedding, the sudden variations in texture and character, as from coarse to fine, from clay to sand and limestone. Fossils are rarely abundant. For this reason, and because of their discontinuity, and variable character continental deposits are hard to trace and correlate from place to place.

Such deposits are commonly red, brownish red and brown owing to the abundance of the red oxide of iron, and the scarcity of organic matter which would tend to reduce the oxides and give the normal dark color to shales and the gray to white color in sandstones.

The vast bodies of red sandstone, arkose, conglomerate and shale, and some limestone composing the widespread Maroon formation, the Weber grits and other formations are of this continental type. The Hermosa in the southwest is more typically marine, as is also its equivalent in the Sangre de Cristo Range.

East of the Front Range the Pennsylvanian was mainly a period of continental deposition, but marine conditions occurred several times and in many places. The formations, Glen Eyrie, Fountain and Lyons, though containing fossil evidence of their age, are notably lacking in remains of the abundant life which characterized the period as shown by the richly fossiliferous Hermosa formation in the San Juan, and the equivalent of the Hermosa of the eastern slopes of the Sangre de Cristo Range.

The Hermosa is widespread in southwestern Colorado and may be regarded as the typical marine Pennsylvanian.

It is a complex of limestones, sandstones and shales. The limestones are rather dense blue-gray, fossiliferous and locally highly bituminous, and range in color from black to gray and greenish. The sandstones are commonly greenish, and both they and the shales are more or less calcareous. At Rico the limestones occur in the middle of the formation, but in other regions the strata change greatly from place to place and are not easily traceable or identifiable.

The Fountain (Lower Wyoming) east of the range may be regarded as representing the continental phase of the Pennsylvanian. It is even more heterogeneous than the Hermosa. Sandstones and arkose of various shades of red and gray, pebbly red conglomerates, red sandy shales and lenticular bodies of limestone rarely of great extent make up strata ranging from 800 to 1,200 feet in thickness. None of the beds are persistent, and changes of composition, color and texture are very frequent.

At the top of the Fountain is a persistent sandstone member laid down in shore waters. It is cross-bedded, thinly laminated and decidedly quartzitic. It varies slightly in color but is generally pink. This is the Lyons.

The Mississippian seas appear to have remained longer in northwestern Colorado, and some geologists think the Pennsylvanian strata lie conformably on the Mississippian, as in New Mexico.

In the Uinta area the Pennsylvanian rocks consist of gray limestone, gray and red sandstone, gray shale and coal, having a total thickness of over 500 feet. These are followed conformably by the Weber quartzite, a fine-grained cross-bedded quartzitic sandstone 900 feet thick. The Weber is probably equivalent to the Lyons or Ingleside east of the range.

The Park City formation follows the Weber quartzite, but whether conformably or unconformably is a matter still in dispute. The evidence seems to point to an obscure unconformity of considerable importance. The formation in Colorado consists of 115 feet of limestone, shale, chert, sandstone and phosphatic shales. This formation contains the rich lead-silver ores of Park City, Utah; rich phosphate rock and oil elsewhere.

The fauna of the Park City has an individuality which makes it difficult to fix the age of the formation, but it is probably Pennyslvanian. The upper part of the formation may be Permian.

The Pennsylvanian was the great coal-making period of the eastern part of the continent, but in the west the geological conditions were not favorable, and there is no workable coal of this age in Colorado.

Pennsylvanian Life

The three Carboniferous marine faunas are clearly a succession, but the advancement of the Pennsylvanian over the Mississippian is much greater than is that of the Permian over the Pennsylvanian.

One type of foraminifera, the Fusulina, was so abundant as to form large bodies of limestone in both Pennsylvania and Permian times. Corals were represented by the simple cup forms but were not abundant. Crinoids had fallen to a very subordinate place. The brachiopods of early Pennsylvanian were the most abundant shelled animals in the seas but they declined rapidly in later Pennsylvanian time. Spined and thick, strongly-marked brachiopods were the most numerous. Pelecypods (clam forms) gained rapidly, but cephalopods outran all other mollusca. Trilobites were scarce, but other crustaceans increased. The eurypterids, a prominent group of Silurian time, still lived.

Insects were very numerous. To the forms of Mississippian time were added bugs, beetles and dragon flies. A dragon fly fossil having a wing spread of 30 inches has been found. Amphibians were represented by nearly 50 genera. The stegocephalians with heavy, platy head coverings were the most striking land animals. Reptiles of primitive types are found fossil.

The plant life of the Pennsylvanian was very abundant and tree forms were dominant. The club mosses or lycopods, of which the Lepidodendron and the Sigillaria are the best known forms, grew to heights of sixty to one hundred feet and stem-diameters of two to six feet. They were the great coal-makers. Sphenophylales were slender, probably climbing plants.

Equisetae—horsetails—had slender stems divided by transverse joints. The stems contained a pith column surrounded by a woody structure. The leaves were variously arranged in star-like radiations and in connected rings. Present day equisetae rarely exceed two feet in height. But some of the Pennsylvanian forms reached a height of sixty to ninety feet. True ferns of both tree and herbaceous varieties were abundant. Many present day types were represented in the Pennsylvanian forests.

Gymnosperms (naked-seeded plants) were represented by cycad-ferns and cordaites. The cycadferns are a connecting link between the flowerless ferns and the flowering cycads. They resemble tree ferns. The cordaites were the only flowering plants, and these had no brightly colored flower leaves. They were very tall, slender trees, having on their tops dense crowns of branches bearing large, simple leaves with straight parallel veining like that of the lilies and grasses. The cordaites were related to the cycads, the conifers, and the ginkgos, but did not belong to any one of these groups.

The forests were dense, gloomy and monotonous—unrelieved by a great variety of plants, or by bright flowers. This flora was very widespread.

"RED BEDS"

The earlier geologists of the Rocky Mountain region gave the name Red Beds to the great series of highly colored sediments upturned against the pre-Cambrian granite-gneiss-schist series east of the mountains, and later to similar rocks beyond the range. In Colorado the Red Beds east of the range include practically all the Pennsylvanian, all the Permian and the Triassic, if any Triassic exists east of the range in Colorado.

West of the range, the Red Beds include the continental

Pennsylvanian, (Maroon in large part, Weber grits), the Permian (Rico and Cutler), and the Triassic (Dolores).

PERMIAN PERIOD

The Permian may be said to have brought to a climax conditions which began in Pennsylvanian time, not only in the Rocky Mountains area but throughout the continent. Widespread continental seas gave place to dry land. The abundant rainfall of the early Pennsylvanian was succeeded by Permian aridity, greatly reduced land waters and scarcity of food. Rock decay was largely mechanical and plant food likewise became scarce.

Permian sedimentation was widespread. Probably all Eastern Colorado is underlain by Permian strata. West of the range rocks believed to be of Permian age are almost as widespread as are those of the Pennsylvanian.

The conditions of life were very hard for both plants and animals, and fossils are remarkably scarce in Permian strata. The red color, the coarse texture, the predominance of sandstones, conglomerates and grits, the scarcity of limestone, and the irregularity of deposition and arrangement of the rock materials all point to climatic conditions such as those of the desert and semiarid regions of today.

In eastern Colorado the semi-continental conditions which characterized the Pennsylvanian continued into Permian time and the conformable Lykins was laid down. The formation consists of red, brown and chocolate sandstones, shales and sandy shales which are locally calcareous and in a few places contain limestone lenses. Cross-bedding and flow-and-plunge structure are very common. Abrupt changes in the character of the material, the texture and the color are very numerous.

West of the range generally and probably everywhere there is a well-defined break between the Pennsylvanian and the Permian strata. In the San Juan there is a pronounced unconformity between the Hermosa of marine deposition and the Rico of mixed continental and marine origin.

The Rico is followed by the Cutler, a series of sandstones, grits, conglomerates, shale and limestone. Grits and conglomerates make up about one-third of the total thickness. Gradations from one lithological type to another are very frequent, and uniformity of material or of stratification is very rare. Cross-bedding is almost universal. All strata are calcareous, and gradations from calcareous sandstones to limy shales and clayey and sandy limestones occur. Pure clays and pure limestones are rare. Gypsum in thin beds occurs in some areas. Red of various shades is the prevailing color, but greenish and grayish tints and even white blotches, streaks and patches give variety to the coloring.

No fossils have been found and the assignment of the Cutler to the Permian is based on stratigraphic relations and lithological resemblances.

PERMIAN LIFE

The life of the early Permian is so much like that of the Pennsylvanian that it is hard to fix the boundary line between the two. But early in Permian time the rising land shut out the continental seas, evaporation became less, and rainfall decreased. Land barriers changed the oceanic circulation and affected the atmospheric circulation. These conditions caused a great reduction of shallow water areas suitable for marine life, reduced the land waters, reduced the food supply, and changed much of the earth's surface into arid and semi-arid wastes.

The stress of life conditions was further increased by the most widespread glaciation known in the history of the earth. The struggle for existence was most severe. All forms of life were greatly reduced, many forms disappeared. By the end of Lower Permian time the entire continent was above sea level, and it remained a land mass until the opening of Triassic time. These hard conditions are portrayed in the prevalence of red rocks with their very scanty content of life remains, their large deposits of gypsum and rock salt and the scarcity of limestone, coal and oil.

A comparison of the known animal species of the Pennsylvanian and Permian periods made a few years ago showed 10,000 for the Pennsylvanian and only 350 for the Permian. Recent study has probably lessened the disparity, but there is not even an approach to equality.

These figures must not be taken as necessarily representing actual conditions. Our search for fossil evidences of life can extend only to the borders of the present continents.

The shallow continental seas of the Pennsylvanian were great gulfs and bays extending inland from deeper oceanic basins which in large measure occupied the same areas as those of today. As the land rose the waters of these gulfs and bays were poured back into the oceanic basins from which they had come. The process was slow and with the waters went their swarming population. But these earth movements greatly reduced the areas of shallow waters, and as the greater part of the life of the seas finds its most favorable habitat in the shallow shore waters, it is evident that the remaining shallow coastal seas, bays and gulfs might be over populated and the struggle for existence become very severe. The weaker forms would perish, and life might be greatly reduced in numbers, species and genera. On the other hand it is conceivable that somewhere on the two-thirds of the earth's surface which was still occupied by waters, favorable climate, abundance of food, and peace permitted the great drama of life to go on in Permian and Triassic times, somewhat as it had in Pennsylvanian. But the story of this, the book of genealogies, lies closed beneath the present ocean floors, and the pages of contemporary history on the continents tell only of hardship, struggle, depletion and extinction for the many. But the triumph of death was only apparent and very unreal, since from this tremendous struggle emerged a higher, better world life and a great advance toward the present had been made.

Marine invertebrates did not suffer very severely in the early part of the period, and corals and cephalopods gained ground both in numbers and in newer and more modern forms. Crinoids became scarce, and trilobites became extinct. Several important brachiopod types declined notably—some of them almost to extinction. Pelecypods were the dominant invertebrates of what is now the Great Plains region. New types of fishes appeared, but the old were still dominant. The amphibians evolved some new genera, especially smaller forms. The reptiles were the most important vertebrates. Several orders and many species of great size have been found fossil, especially in New Mexico, Oklahoma and Texas. Insects became smaller and more modern in type.

The early Permian plant life was but a lightly modified Pennsylvanian flora, but the unfavorable geological, geographical and climatic conditions caused great changes before the end of the period. Of the important Pennsylvanian types the lepidodendrons, the sigillaria and the calamites died out. Ferns advanced notably. The Gymnosperms (naked-seeded plants) advanced rapidly, and included cordaites, cycads, ginkgos and conifers. The most conspicuous floral change was the appearance of the glossopteris (tongue fern) flora which evolved in the area of Permian glaciation and spread very widely.

Chapter 3

GEOLOGIC ERAS

MESOZOIC AND CENOZOIC

MESOZOIC ERA

The life of the earth made great evolutionary progress during the Paleozoic Era. A comparison of the life of the Cambrian with that of the Pennsylvanian would impress the observer by its contrasts rather than by its similarities. In the intervening time many forms unknown to the Cambrian had risen, reached their highest development and disappeared. The early Paleozoic may be called the age of invertebrates, the Devonian or mid-Paleozoic is termed the age of fishes, and the late Paleozoic the age of amphibians.

These are the old life (Paleozoic). The progress of life from the Cambrian to the Pennsylvanian was rather even and steady. But the apparently adverse conditions of the Permian and Triassic appear to have given a remarkable impulse to the current, and there followed an unparalleled acceleration of the evolutionary process, marked by numbers, size, physical organization and the development of brain. This has led to the name Mesozoic or middle life for the next great era of earth history. In a general way the life of the Mesozoic may be said to stand midway between that of the Paleozoic and that of the Cenozoic or new life, essentially the present.

TRIASSIC PERIOD

East of the range there is but little satisfactory evidence of the existence of Triassic strata, though a pinkish gray sandstone lying on the Permian near the Wyoming line and a similar sandstone in the same relationship in the southeastern part of the state may be Triassic. In Northwestern Colorado the Permian is overlain by a dark red ripple-marked and rain-printed shale, above which are sandy strata followed by shale and limestone containing Triassic fossils. Two hundred feet of red and gray sandy shale, sandstone and grit resting on the limestone may also be Triassic.

In the southwest the Dolores, Triassic, is unconformably on the Cutler, and consists of sandstones, shales and fine grained conglomerate, all more or less calcareous. In the lower part is a conglomerate composed largely of small limestone pebbles. The upper part is fine even-grained red sandstone and shale, with a strong cliff-making gray to pink sandstone at the top. The "bone conglomerate" or "saurian conglomerate", a very interesting part of the formation, contains many teeth of crocodiles and saurians and many bones and bone fragments. Along the White River Plateau Triassic rocks occupy considerable areas, and a "bone conglomerate" fixes their age beyond doubt.

The Cutler and Dolores formations by their great variety of material, their varying degrees of resistance to erosion, their brilliant and yet varied coloring have made possible the development of one of the scenic fairy-lands in this country. Steep walled canyons of brilliant but always harmonious coloring, benches and shelves, spires and turrets, glens and caverns, tree-crowned cliffs and grassy basins abound in a startlingly beautiful though but little known part of Southwestern Colorado.

The Triassic closed with a widespread elevation of the land in the Rocky Mountain region, and while sedimentation may have continued uninterruptedly from Triassic to Jurassic in limited areas, the general relations of the Jurassic to the Triassic rocks are unconformable. Before the close of the Triassic time life conditions began to improve, and the greatly impoverished fauna and flora showed many signs of revival. The opening of the Jurassic continued and hastened the progress of recovery, and there began in America the most notable period of expansional evolution known in geological time.

Triassic Life

The distressing conditions of Permian time continued into early Triassic, and the lower Triassic formations contain very few fossils. Soon after the middle of Triassic time conditions improved, but it was not until early Jurassic time that there was a complete return to normal climate and environment.

The strenuous conditions through which life had passed seem to have preserved, developed and strengthened those functions, habits, structures and features best fitted to cope with the hard times. When conditions improved many new types appeared, and the less favored or less progressive older forms dropped out of the race.

Amphibians dropped from first place and entered upon a decline from which they never recovered. The reptiles evolved rapidly especially toward the close of the period, when the climate improved. They included crocodiles, both marine and terrestrial, flying saurians (related to the lizard), true lizards, and snakes. The dinosaurs were the dominant types. In some respects the saurians foretold the advent of birds. Marine saurians appeared as the seas of late Triassic time invaded the land, and 40 genera and 92 species of land reptiles have been found fossil in the Connecticut valley alone.

Small, primitive types of mammals, possibly related to the pouched mammals or marsupials, came in but no placental mammals had yet appeared.

Of the marine invertebrates, the brachiopods, trilobites, crinoids and corals of the Paleozoic were all forced into the background, and in their places two molluscan forms, the ammonites (coiled cephalopods) and the pelecypods take first and second places. The ammonites were represented by 1,000 species. Brachipods were never again very abundant, but new forms with long hinge lines and prominent beaks appeared.

Conspicuous among new invertebrate forms were the cuttlefish, new species of gastropods and new pelecypods. Some of the pelecypods were very modern in appearance, and a few were identical with living types.

The crinoids gave place to the sea urchins. Corals flourished in favored places and the compound species were of the modern type.

The dominant plant life included ferns, horsetails, cycads and conifers, and the coals of Virginia, North Carolina, the Keuper coal of Germany and Sweden, and the Triassic coal of South Africa and Australia are formed from accumulations of these plants. Cycads were very numerous, and the Mesozoic is sometimes called the "Age of Cycads." Conifers in dense forests occupied the hills and uplands. They resemble the Araucarians of South America, Polynesia, and Australia. Cypress-like trees, the Voltzia, were also common.

The forests were still gloomy and monotonous. No bright flowers, and very little variety of foliage relieved the sameness of the vegetation. The present day fern forests of New Zealand may give some idea of the appearance of the Triassic forests.

JURASSIC PERIOD

Land conditions prevailed over the greater part of the North American continent through Lower and Middle Jurassic time. In Upper Jurassic time the seas again invaded the continent, but it was not until at least the middle of Upper Jurassic that they reached the Rocky Mountain region, and their stay was but short. In them were laid down formations of almost equivalent age known as the Sundance, the La Plata, the Nugget (in part at least), and the Twin Creek.

The Sundance occurs east of the range in Colorado as thin upturned strata of creamy white to buff sandstone in unconformable contact with the Lykins, from the Wyoming line southward to the Cache la Poudre. West of the range it occurs in the vicinity of Hahns Peak and along the White River Plateau, where it consists of light to dark gray limestones, sandstones and shales. Fossils are abundant in the Hahns Peak area.

In northwestern Colorado the Nugget formation consists of fine grained, cross-bedded, poorly cemented white to buff sandstones with some red and gray shale near the top. The Twin Creek is a light gray fossiliferous limestone with some marine shales at the base.

It has been suggested that the La Plata of southwestern Colorado was deposited by wind in the form of dunes, and later worked over, in part at least, by fresh water. The absence of animal fossils, the uniformity of texture and the structural features of the formation are not out of harmony with this suggestion. But its very wide distribution and the fairly constant division into an upper and a lower heavy sandstone, and an intermediate thin bedded and limy division are hard to account for under conditions of wind deposition.

In the Gunnison area the equivalents of the La Plata and the McElmo were formerly called the Gunnison.

After the retreat of the Jurassic seas fresh-water basins occupied large areas in the Cordilleran zone and in parts of the

Pacific northwest. In these basins were laid down vari-colored marly shales, limestones and sandstones. These lake basins were surrounded by low-lying plains rich in vegetation and inhabited by great dinosaurs, and primitive mammals, the bones of which are found in considerable numbers in the lake beds, along with the shells of fresh water mollusks and fossil plants.

These beds are known as the Morrison east of the range, and they outcrop interruptedly along the flanks of the range from the Wyoming line to New Mexico and they probably underlie much of eastern Colorado as erosion has exposed them in numerous places. In western and southwestern Colorado they are called the McElmo and are exposed in many of the larger valleys and along the Uncompahgre Plateau and the slopes of the La Sal Mountains.

Jurassic Life

The improvement in life conditions which began in late Triassic time continued increasingly through Jurassic. The climate was genial and without seasonal stresses, rainfall increased and food became abundant on the land, in the shallow shore waters, and in the invading seas which were gradually making their way over the continents. In North America the transgression of the seas made little headway until the latter half of the period, and then only in the west.

The Jurassic inherited from the Permian and Triassic meager but well seasoned, tried and proved faunas and floras—children of adversity—needing only the magic of suitable environment to cause them to multiply, replenish and repossess the earth.

It is impossible to give in short space more than the most sketchy picture of the marvelous evolutionary progress of the Jurassic.

Reptiles take first place in both sea and land faunas, and of the reptiles the dinosaurs were easily supreme. Turtles, crocodiles, lizards and others of the 18 Mesozoic reptilian orders played their part in the life drama, but for the leading role the dinosaurs had no rival. They ranged in length from a foot to 80 feet, in height from a few inches to 20 feet, and in weight from 10 pounds to 40 tons. By structure and adaptation to environment they ruled sea, land and air. There were herbivorous and carnivorous forms, some walked or ran on four legs, others were equally swift on two. Some swam the seas and the lakes and wallowed in the marshes. Others equalled the birds in flight, using membranous wings like those of the bat. Some were unprotected by armor, but others carried head and neck armor, and still others body plates of great weight.

Turtles were inconspicuous, but fossil remains are found in the Morrison formation. The crocodiles were numerous in both marine and fresh waters. Little is known about Jurassic lizards but they certainly existed.

The Morrison and McElmo formations are fresh water Jurassic sediments, and the Morrison of Colorado and Wyoming has yielded a very rich harvest of Jurassic fossils. These include 69 kinds of dinosaurs, 25 primitive mammals, one bird, one pterodactyl, one turtle, 3 crocodiles, 3 fishes, 24 invertebrates, 23 plants, and a frog.

The only mammalian fossils of Jurassic age yet found are those of very small primitive forms, probably of the pouched insectivorous type. Jurassic birds had many reptilian features but were clothed with feathers, and were highly developed. The fishes began to assume a somewhat modern aspect. Skates and rays were numerous. Seacats (spook-fish) appeared. The ancestors of the garpike and the sturgeon were most numerous, and the ancestors of the teleosts (bony-fishes) appeared. The descendants of the Triassic land reptiles, such as the ichthyosaurs and the plesiosaurs became very abundant in the seas, and might be called Jurassic sea serpents. Insect life was represented by several of the orders.

The invertebrate marine fauna was very abundant. Corals and crinoids showed a distinct revival in late Jurassic time, but no Paleozoic crinoids remained. Crabs, lobsters and prawns represented the crustaceans, and presented modern features. Pelecypods of modern appearance were very numerous. Oysters were abundant. The ammonites were the dominant invertebrates, and were represented by both advanced and decadent forms. The latter were prophetic of the disappearance of the group in the Cretaceous. Belemnites—cephalopods with internal shells and two gills—were very numerous. The Sundance formation in Routt County is very rich in belemnite fossils. Sponges were very abundant, and foraminifera and radiolaria were widely distributed.

The Jurassic flora is a continuation of that of Triassic time, and consists of ferns, horsetails, cycads, conifers, and ginkgos. Of these the conifers showed the greatest advance toward modern types, and included yews, cypresses, cedars and pines, though not of species now living.

In Europe many land plants were buried in marine sediments along the Jurassic sea coasts.

CRETACEOUS PERIOD

The close of the Jurassic was a time of great land emergence and the continent was probably larger than it is now. In early Lower Cretaceous time a sea covered part of eastern Mexico, and from this area it invaded the United States, but it did not reach Colorado until late in Lower Cretaceous time and only the latest of the three divisions of Lower Cretaceous (the Washita), is present in the state. This invading sea gradually extended northward over what is now the mountain zone until in early Upper Cretaceous time it joined a great southward advancing arm of the Arctic Ocean and with it formed a continuous mediterranean sea the length of the continent. In the Colorado part of this sea in the area of the present mountains were laid down in conformable succession the "Dakota", the Benton, the Niobrara, the Pierre, the Fox Hills, and the Laramie formations, making in places a total thickness of Cretaceous sediments, mainly shale, of 10,000 feet or over.

The Benton and Niobrara form the Colorado group, and the Pierre and Fox Hills are the Montana group. West of the range a similar conformable series consists of the Post-McElmo, "Dakota," Mancos, Mesaverde, Lewis, and Laramie.

The "Dakota" consists, as a rule of two sandstone members separated by a body of shale. The lower sandstone and the shale are marine beds of Lower Cretaceous age, and the upper sandstone is of fresh water origin, and Upper Cretaceous age.

The Lower Cretaceous division is called the Purgatoire. In the Colorado Springs area the members of the Purgatoire are called the Lytle sandstone and the Glencairn shale. Farther north they are called the Lakota sandstone and the Fuson shale. The pebbly conglomerate at the base of the Purgatoire is one of the most persistent and easily recognized beds in the Rocky Mountain region. West of the range the Post-McElmo and the lower members of the "Dakota" contain a Lower Cretaceous flora and must be considered as the near equivalent of the Purgatoire.

The Upper Cretaceous part of the "Dakota" both east and west of the range is a strong sandstone. In the east there is an abrupt change to the overlying Benton shale, whereas in the west there is a coal-bearing transitional group between the sandstone and the typical Mancos. These coal-bearing beds have also been classed as Mancos, but present usage seems to favor their assignment to the Dakota.

Both sandstones of the "Dakota" yield artesian water in eastern Colorado, and both are oil-bearing in Wyoming and possibly in the northern Colorado fields. The opening of the Benton marks the change from fresh water to marine conditions which continued until nearly the close of Cretaceous time. The strata consisted of 200 to 400 feet of dark gray to blue-gray shales with thin sandstones and limy layers, the Graneros, followed by 25 to 150 feet of limestone, the Greenhorn, and a varying thickness of dark gray shales with thin sandstones and limestones near the top, the Carlile.

The Benton underlies most of northeastern Colorado, and is exposed in a large area along the Arkansas River and as cappings on the Dakota south of the river. It is the greatest oil producer of Wyoming, but has not yet yielded oil in Colorado.

The Niobrara consists of a heavy gray limestone at the base followed upward by an alternation of limestone and light colored limy shales. This lower member is the Timpas. In many places the basal strata are chalky. Overlying the Timpas is a series of several hundred feet of gray to black shale, limy shale, and a few strata of sandstone and cream-colored limestone. This is the Apishapa.

The Pierre is mainly a grayish-black shale series ranging in thickness from 1,300 feet near Trinidad to 7,700 feet near Denver. Sandstone lenses and strata break the monotony of the formation in northern Colorado and some thin limestone occurs at various points. The sandstone strata are distributed irregularly through a vertical distance of 1,800 feet, to which has been given the name Hygienic zone after the most persistent sandstone member. The formation underlies all northeastern Colorado and extends east into Nebraska. South of the Arkansas River there is but little Pierre except in the Trinidad coal field. It yields the oil of the Florence and Boulder fields.

The Fox Hills may be regarded as a sandy upward continuation of the Pierre. Near the foothills the formation is very largely sandstones, but eastward it is less and less sandy until it is difficult to draw any line between it and the Pierre. In its northern outcrops the heavy upper sandstone is called the Milliken. In the south a similar member is called the Trinidad. Above these are others not specifically named except in the Trinidad coal field where the lower coals are associated with a sandstone called the Vermejo.

The Pierre shales were laid down in marine waters, the Fox Hills formation in brackish waters and the Laramie in fresh waters. The first fresh water deposition was that of the Vermejo in the Raton coal field, and it is probable that there was never a complete return to marine conditions east of the range in Colorado.

The Laramie consists of a rather persistent basal sandstone overlain by an alternation of shales and lesser sandstones and coals. Along the foothills the stratification is fairly regular, but farther east it is extremely irregular. Cross-bedding, lenticular bedding, rapid alternations of shale and sandstone are characteristic.

There is a pronounced break in the fauna between the Fox Hills and the Laramie. The formation is present in the greater part of a triangular area between the foothills and a line drawn from Colorado Springs to the northeast corner of the state.

If the Laramie as now delimited east of the Front Range is taken as the typical or true Laramie it is doubtful whether there is any true Laramie west of the Front Range, in Colorado. The "Laramie" of the San Juan, the Grand Mesa, the Grand Hogback and many other areas contains a pre-Laramie or Montana fauna at the base. In the vicinity of Craig the Lewis shale is overlain by a series of shales, thin coal beds and prominent sandstones.

In the basal part of the series is a pre-Laramie or Montana fauna, but in the top there are Laramie plant fossils. This may be a transition to true Laramie.

The Mancos of western Colorado is roughly the equivalent of the Benton, Niobrara and lower Pierre. It consists of gray to black shales with a few limestone and sandstone strata. Benton and Niobrara fossils are locally abundant in the lower part of the Mancos, and Pierre fossils occur in the upper part. The formation ranges from 3,000 to 5,000 feet in thickness.

The Mesaverde is the great coal-bearing formation of Colorado, New Mexico, Utah and Wyoming. It consists of a series of alternating sandstones and shales of Lower Montana (Pierre) age, containing several seams or groups of seams of coal. A prominent feature of the formation is the development of massive cliff-making or ridge-making sandstones.

Overlying the Mesaverde is the Lewis shale, a marine formation containing a Montana fauna. These relations show that the Mesaverde represents a period of fresh water, coal-making conditions within Montana time. Moreover, the evidence shows that the time of the beginning of such coal deposition was not the same in different parts of the area in which Mesaverde coals occur in New Mexico, Colorado, Utah, Wyoming. It was earliest in the south. The Lewis shale resembles the Mancos, but is more variable in character, and in a few places is coal-bearing, and in several places coal-bearing strata conformably overlying the Lewis contain fossils which seem to relate them more closely to the Montana than to the Laramie east of the range.

The "Laramie" of the southwest rests conformably on the Lewis. It consists of a basal sandstone member called the Pictured Cliff sandstone, followed by shales and coal. The series appears to be transitional from Montana to Laramie. The flora is distinctly Montana in type, the vertebrate fauna is older than Laramie and the invertebrate fossils might be classed anywhere within the group from the base of the Fox Hills to the top of the Lance.

The coal series of the Grand Mesa field at the south end of the Uinta basin is probably of the same age as that of the "Laramie" of the San Juan—either late Montana or transitional from Montana to Laramie. The Rollins sandstone at the base may be equivalent to the Pictured Cliff sandstone, and the Bowie and Paonia coal-bearing shale members may represent the coal-bearing "Laramie" series of the San Juan basin.

The "Laramie" of the Yampa and other northwestern coal fields consists of a thick group of sandstones and shales containing seams of workable coal of fair grade. The formation is conformable on the Lewis and the invertebrate fossils found are of Montana (Lewis) affinities. It is more closely related to the "Laramie" of the San Juan than to the Laramie of the Denver basin.

In later Fox Hills time in eastern Colorado parts of the great Cretaceous sea were converted into brackish and fresh-water lagoons, deltas and swamps, and in them were laid down the lower coals of the Trinidad field. Whether the entire conformable series was completed in this area we do not know, but if it was, there followed a land period during which the entire Laramie and a part of the Vermejo were eroded away, and a much later formation, the Raton, also coal-bearing, rests unconformably on the Vermejo.

Farther north the Fox Hills was marine or brackish water to the end, and it was closed by a gentle uplift which converted a part of the sea floor into land, but left a large area bordering the mountains and stretching far to the northeast occupied by brackish and fresh-water swamps and lagoons in which were deposited sandstones, shales and coal in stratigraphic conformity with the underlying Fox Hills.

These beds are the Laramie formation. They are as a rule discontinuous and suddenly variable both in structure and composition, but there are a few strata which are notably continuous —particularly the great basal sandstone resting on the similar Fox Hills strata. Between the fossiliferous Fox Hills and the fossiliferous Laramie are beds barren of fossils, and the Laramie flora and fauna bear little or no resemblance to those of the Fox Hills.

CLOSE OF THE CRETACEOUS

By late Laramie time the great mediterranean sea basin which in its widest part reached from central Utah to central Nebraska and Kansas, had received deposits of Cretaceous shale, sandstone, limestone and coal in thickness ranging from 2,000 feet in the border area to approximately 12,000 feet in the vicinity of Denver. Filling, and probably gentle elevation, had brought the sea floor almost to sea level, and in eastern Colorado and far to the north and northeast there remained only brackish and fresh-water lakes and lagoons in which coal deposits were being made. Marine conditions may have continued a little longer in central and western Colorado.

The mountain-making process began as an irregular arching of this broad zone until the central part reached an elevation of 5,000 to 6,000 feet. Stresses accumulated in the central and western portions and a line of weakness developed where the eastern foothills now stand. The mountain mass was thrust up dragging with it and steeply upturning the sediments which extended across the zone of weakness, far onto the upward moving mountain block. Along this zone of weakness the differential movement reached several thousand feet, and the rocks are stretched, folded, faulted and crushed.

Accompanying this upheaval and continuing after the major movement had ceased, were tremendous outpourings of lavas which covered great areas, intrusions of vast bodies of molten rock which did not reach the surface, and explosive volcanic eruptions which scattered volcanic ash and other fragmental material far and wide in such quantities that great thicknesses of sedimentary beds were made from them.

The results of this period of upheaval are the great mountain ranges and groups of the state, for they all belong, in the main, to this general period, though many lesser movements added to them. The igneous activity also recurred at intervals during Tertiary time, and the last outbreaks were probably as late as Pleistocene or Recent time.

Cretaceous Life

Vertebrates are the dominant feature of Lower and Upper Cretaceous life. Sharks of modern type, and herring, cod, salmon, mullet and catfish were plentiful in the Upper Cretaceous. Large carnivorous fish—the saurodonts, inhabited coastal waters. The amphibians were losing ground, but the reptiles held sway in the sea, on the land and in the air until nearly the close of Cretaceous time when the mightiest, most diverse and the most fantastic animal dynasty that ever appeared suddenly fell, leaving only an insignificant posterity for the present.

Turtles and crocodiles inhabited both fresh and marine waters. Lizards and snakes made slow progress. The mammals also advanced rather slowly, were modest in size and few in number. In late Cretaceous they began to show Cenozoic features.

The birds had made notable progress, and there was already much diversity in size and power of flight. Some had powerful wings, while others could not rise from the ground, but used their wings to aid their legs. The hesperornis was a wingless bird of reptilian form having toothed jaws. The ichthyornis was a winged aquatic bird of reptilian type, having toothed jaws.

The mollusks were very numerous and oysters of enormous size were common. Gastropods made great progress and straight, regularly coiled and irregularly coiled forms existed. Ammonoids declined. Corals, and brachiopods were scarce in the great western interior sea, and crinoids had declined. The Cretaceous corals resembled those of today. Insects of many modern types were plentiful.

The plant life of the Jurassic continued into the Lower Cretaceous and was characterized by ferns, horsetails, conifers, cycads and bennetites. The notable change is the appearance of angiosperms, sparingly in Portugal, but very abundantly in eastern and central America. They included both monocotyledons and dicotyledons, developed very rapidly, and, though scarce in the earliest Comanchean rocks, they are the dominant types of plants in the upper beds, and have yielded 400 species. Many genera are similar to those living, and include figs, magnolias, tulip trees, laurels, and cinnamon. The cycadeans had become scarce, and conifers and ferns were also reduced in numbers.

Flowering plants predominated even at the opening of the Upper Cretaceous. Before its close, the flora took on a decidedly modern appearance. The forests included the oak, beech, walnut, birch, sycamore, tulip tree, laurel, maple, holly, cinnamon, oleander, and other present day fruit and nut-bearing trees. The conifers included the sequoias (the giant trees of California). In later Cretaceous times, monocotyledons became prominent and included the palms and grasses.

The flora spread rapidly, and no climatic zones seem to have hindered its progress. In many respects, it resembles the subtropical flora of today, though it extended as far north as middle Greenland.

CENOZOIC ERA

The close of the Createaceous with its great mountain-making upheaval witnessed the final withdrawal of the seas from the state and from nearly all the Rocky Mountain region. The mountain upheaval had changed the surface of the state from low-lying plains to a vast western plateau having an average elevation of 8,000 feet, a mountain zone much of which stood over 14,000 feet above sea level, and a broad eastern plain sloping from an elevation of 7,000 feet against the mountains to about 4,000 feet at the eastern margin of the state.

In Eastern Colorado there were no seas and probably no salt lakes, during Tertiary time. The rocks of this period were laid down in great shallow fresh-water basins, and by flooded rivers whose valleys were ill-defined and whose channels were constantly changing. The rocks include sandstones, conglomerates, shales, limy sandstones, and limy shales or marls grading into limestone. The bedding is extremely irregular and the character of the rocks changes very rapidly both vertically and laterally. The rapidly changing conditions were not generally favorable for abundant life, either plant or animal, although locally it was very plentiful.

At first the drainage of all these areas would be such as to afford little chance for the development of lake basins in which sediments could be deposited. But along the borders of the mountains where the gradient of the rivers changed rapidly from their torrential mountain courses to the gentler sloping valleys on the plains, lake basins were formed and much coarse material was deposited as great alluvial fans or deltas spreading far into the basins. Beyond these coarser sediments, the finer sands and clays were laid down in more regular and continuous beds. We may divide the Tertiary rocks of eastern Colorado into two groups:

1. Eocene—all of those just east of the mountain front, from northeast of Denver south to Colorado Springs, and those of the Trinidad-Walsenburg-Spanish Peaks area—a total of about 4,500 square miles.

2. Oligocene and later—all those along the northern border of the state, and the broad eastern belt from the South Platte to the New Mexico line, 17,500 square miles.

Just north of the Arkansas, this belt extends westward and overlaps the Eocene area in the eastern part of El Paso County. South of Township 11 south, or south of parallel 39°, the Arkansas River and its tributaries have cut their valleys through the Tertiary formations and have completely removed them from large areas, exposing the Cretaceous formations and in many places all the later Cretaceous strata have also disappeared.

TERTIARY PERIOD

Eocene

East of the Front Range coarse and irregular deposits were formed along the mountain front. One of these extends from Boulder County to El Paso and eastward from the foothills 40 to 50 miles. It has an average thickness of several hundred feet and a maximum of 2,500 feet.

Various names have been given to different parts of the formation on the supposition that they were of different ages. The different parts are deposits of one period brought to the basin by different streams from different areas. The Dawson part is mainly granite debris, the Arapahoe is largely crystalline rock waste, and the Denver is mainly andesitic debris from a volcanic area, with granitic sand at the top. The Cuchara and Poison Canyon formations of Huerfano and Las Animas counties consisting of pebbly conglomerate, coarse cross-bedded sandstones, sandy shales and greenish yellow and brownish red clays were laid down under similar conditions, but a little later.

Numerous formations in central and western Colorado are almost the exact equivalents of the Arapahoe and Denver both in fossil content and material make-up. Among these are the Middle Park Beds, the Animas Beds near Durango, the Ohio Creek and Ruby of the Anthracite and Crested Butte region. The San Juan tuffs are probably of about the same age. The Torrejon and Puerco formations which overlie the Animas Beds southeast of Durango are of the same general age. They are made up of shales and soft sandstone of various colors from gray to red and black.

All the older reports on the Tertiary of northwestern Colorado describe a conformable series of great thickness including the Wasatch, Green River, Bridger and Uinta. More recent study leads to the conclusion that the Wasatch and Green River are phases of the same great series of sediments, deposited under conditions similar to those which prevailed in the Denver Basin during the deposition of the Dawson, Arapahoe and Denver "formations."

Rivers from the recently uplifted Uinta, Park and Wasatch ranges carried their loads of sediments into the bordering lowlands, building alluvial fans which in places coalesced and formed lake basins, swampy areas and floodplains in which regularly stratified beds of finer materials were laid down and in which plant materials might grow for the making of coal or oil shale.

Under certain conditions long arms or tongues in which such lacrustine conditions (Green River) prevailed would stretch far into the normal Wasatch territory of coarser sediments, as in the case of the Tipton tongue and the Laney shale member of the Green River.

Again the Wasatch type of sedimentation would transgress the Green River territory and the Cathedral Bluffs tongue of Wasatch was formed.

The most notable feature of this twin formation is the great deposits of oil shale containing the possibilities of an oil supply far exceeding the well oil resources of the whole United States. These oil shales are most richly developed in Colorado, but Utah and Wyoming have inherited vast treasures of this material.

The Wasatch phase of the formation is largely fluvatile and consists of variously colored clays and sandy clays alternating with crudely bedded sandstone, grits and conglomerates. The sandstones are mainly gray, buff and brown, but white, pink and red beds occur.

The Green River phase is largely lacrustine sediments consisting of coarse brown sandstones, at the top, and finely laminated shale, interbedded with oil shales below. Parts of the formation are highly calcareous and silicified oolitic limestone, and calcareous algae reefs occur.

The Wasatch of southwestern Colorado is a more homogeneous formation of variously colored sandstones and shales with a massive cliff-forming basal sandstone.

The Bridger consists of river and lake deposits of ash-gray and drab clays or marls with a few bands of vivid green sandy layers or sandstone. Thin limestone and conglomeratic beds occur. The formation weathers into bad lands topography. There is an unconformity between the Bridger and the Green River.

The Huerfano of the Trinidad area is of Bridger age. It consists of a great body of heavy-bedded coarse sandstones, in many places cross-bedded and conglomeratic. Near the base are clays and marls. The whole formation is brown or reddish brown.

The Raton formation lies unconformably on the Vermejo in the Trinidad coal field, and consists of 1,800 feet of brown to buff sandstone, yellow to black carbonaceous shale, and numerous coal seams. There is usually a conglomerate at the base.

The Arapahoe is coal-bearing in the vicinity of Scranton east of Denver.

The Coalmont of North Park is a great body of coal-bearing strata consisting of sandstone, conglomerate, shale and coal resting unconformably on the Pierre, and assigned to the Lance on the rather insufficient evidence of poorly preserved plant remains.

Coal-bearing strata believed to be later than Laramie and, therefore, probably Eocene, occur in Moffat and Routt counties. They are overlain by Wasatch, Eocene. In a few places in northwestern Colorado there are thin coal seams in the middle part of the Wasatch. In the White and Grand River coal fields certain strata at the very base of the Tertiary (Wasatch) are believed by some geologists to be of Fort Union age.

Oligocene

The White River of northeastern Colorado is commonly divided into the Chadron and Brule. The Chadron is composed of about 200 feet of poorly consolidated strata mainly of sandy clays, and greenish-gray sandstones, mostly of soft texture. The beds are notably discontinuous and suggest channel deposition. The Brule consists of massive hard sandy pale-pink clay having a thin stratum of limestone near the base. In many places in eastern Colorado beds of gray volcanic ash occur in the Brule. Fossils of mammals and turtles are common in some localities. The White River underlies a very large area in northeastern Colorado but outcrops are narrow owing to the nearly equal distribution of the overlying Miocene and Pliocene.

A series of sandstones and shales in the southern part of Middle Park is assigned to the Uinta, but on no very convincing ground. The Uinta of the Uinta Basin is probably represented by the Browns Park.

The Castle Rock Conglomerate of the Castle Rock quadrangle is of White River age, and belongs to the Chadron.

MIOCENE

The Browns Park Formation occupies a large part of Moffat County, extending in a widening band from Craig westward to the Utah line. It unconformably overlies rocks of all ages from Paleozoic to Tertiary. It reaches a maximum thickness of 1,500 feet or more. The basal part of the formation is a sandstone containing conglomerate beds composed of granite, gneiss, schist, quartz and quartzite pebbles. Above this the greater part of the formation is soft, white sandstone of chalk-white color, and poorly cemented with lime carbonate. The age is uncertain, but the only fossil evidence suggests Miocene, or uppermost Oligocene.

The Bishop Conglomerate occurs as small caps on Diamond Peak and Lookout Mountain and other high points in Moffat County. It is very probably a series of remnants of the basal conglomerate of the Browns Park Formation.

The Santa Fe formation outcrops upon the older sedimentary and igneous rocks almost entirely around the San Luis Valley. So far as exposures are concerned it is the oldest of the Tertiary lake beds flooring the park. It consists of conglomerates, sandstones, gravels and clays. The materials contain much igneous debris and waste from the older formations.

Similar beds along the Rio Grande near Creede are believed to be of the same age as the Florissant. The Florissant beds contain a rich flora and an insect fauna commonly assigned to Miocene age. The strata are largely of volcanic ash. The

Alnwick and High Park Beds are not definitely assigned as to age but are believed to be later than the Florissant Beds in the same general area.

Miocene and Pliocene

The Arikaree is in many places unconformably on the White River and consists of loosely consolidated sands and sandstones in which are many irregular calcareous concretions especially in the lower part. Overlying these deposits unconformably are deposits of sand and gravel and calcareous grits, "mortar beds," called the Ogalalla. On the basis of vertebrate fossils the formations are assigned to "latest Miocene or first phase of Pliocene."

The Nussbaum loams, sands and gravels capping divides and other high areas in parts of southeastern Colorado have been correlated with the "Tertiary grit" and "Plains marl" described by Kansas geologists, and supposed to be of Pliocene age. It is possible that in some cases this correlation is correct, but it is probable that in a number of cases these deposits are of Pleistocene and Recent age.

Pliocene and Pleistocene

The Alamosa consists of a series of alternating sands, gravels and clays unconformably on the Santa Fe. It is the great artesian water-bearing formation of the San Luis Valley. On the evidence of fresh-water fossils it is assigned to late Pliocene or early Pleistocene. The formation is composed of materials carried by streams from the surrounding higher country into the great San Luis lake basin.

QUATERNARY PERIOD

Pleistocene and Recent

The principal deposits of Pleistocene and Recent times in Colorado are alluvial gravels, sands and loams along the stream courses; wind blown sands, dunes and loess back from the streams and on the plains in general; moraines in the higher mountain valleys; and peat and swamp muck in disappearing glacial basins and swampy floodplain areas.

In Pleistocene time glaciers occupied large areas in the higher ranges and probably at times coalesced into ice caps of considerable extent in the San Juan, the Sangre de Cristo, the Medicine Bow, Park and Front ranges, and individual alpine glaciers were very numerous.

The geological work of today consists in the weathering, breaking down and removal of debris from the surface of the state, the conversion of hard rock into soil, and the preparation of plant food by the decay of rocks.

CENOZOIC LIFE

Almost all the lower groups of animals had become modern in character. The trilobites, brachiopods, ammonites and others had given way to modern groups of crustaceans, bivalves, cuttlefish and others.

Fishes, amphibians and reptiles had passed their prime, and the species resembled those of today. The birds exchanged the bony, toothed, reptilian jaws for the present type. The long vertebrated tail disappeared. Flightless forms such as the ostrich were common in Cenozoic time and some have persisted to the present.

Mammals became the dominant type, but these were in many respects different from those of today. Generalized forms were common, and it is not possible to group Tertiary mammals so definitely into Carnivores (flesh eaters); Ungulates (hoofed animals); Rodents (gnawers); Cetaceans (whales and dolphins). These generalized forms had features belonging to several of the present day groups. The horse, deer and rhinoceros families with their special and distinct features may be traced back to a peculiar five-toed animal having a full set of rather simple teeth, and of no greater size than an average dog. The dog, cat and bear families are traced to an animal similar to the ancestor of the horse, deer and rhinoceros.

Evolution was very rapid, and bone deposits show remains of both the modern differentiated forms and the earlier generalized types. By middle Tertiary the main divisions of the Mammals were distinct, and cats, horses, monkeys, whales, bats, elephants and many other kinds were represented, but the forms were not just the same as those now living. For example, the horse had three toes.

A very large part of the plant life took on modern forms in early Cretaceous times, and, while the genera were in many instances the same as those now living, the species were different. In early Tertiary times, even the species became, in large part, modern.

The flora of the Denver beds (Eocene) contains figs, poplars, laurels, magnolias, and many ferns, and is similar to that of the Eocene of southern British Columbia, 630 miles farther north. In many temperate zone areas, the Middle Eocene flora was tropical in aspect, and Greenland and Alaska had temperate zone floras, with luxuriant forests.

Prominent among the Eocene trees of America were: the banana, palms of many varieties, myrtles, beeches, oaks, willows, poplars, sycamores, elms, laurels, magnolias, maples, walnuts, pines, spruces, cedars, and others.

Grasses took possession of all open spaces in Miocene time, and the general character of the vegetation even to the northern limits of the United States, was subtropical. In the volcanic tuffs of the Yellowstone Park are buried poplars, oaks, hickories, elms, maples, magnolias, and sycamores. The bread-fruit grew in Oregon. But the subtropical types gave way largely to temperate zone forms before the close of the period. At Florissant, the flora was of a warm temperate character, and contained sequoias and other trees of similar habits.

Zonal divisions of climate became prominent in the Pliocene, and with them there was a gradual withdrawal of tropical and subtropical species to their present habitats, and the temperate flora became the prevailing type over a large portion of North America.

STRATIGRAPHY

NORTHWEST COLORADO

Era	Period	Epoch	Formation
Cenozoic	Quaternary	Recent	Soils and alluvium
		Pleistocene	Local glacial deposits
	Tertiary	Pliocene	Probably not represented
		Miocene	Browns Park Bishop Conglomerate Probably only basal part of Browns Park
		Oligocene	Not known in N. W. (Unconformity)
		Eocene	Bridger (Unconformity) Green River Wasatch (Unconformity) Ruby, Ohio Creek
		Eocene (?)	Post-"Laramie" (Unconformity)
			"Laramie"
Mesozoic	Cretaceous	Upper Cretaceous	Lewis Mesaverde consisting of *a* Williams Fork *b* Iles Mancos Dakota Group: Dakota Upper Part
		Lower Cretaceous	Dakota Group: Lower Part (Unconformity) Morrison is possibly Lower Cretaceous

Mesozoic		Jurassic	Morrison (McElmo, Flaming Gorge)
			Twin Creek (Sundance)
			Nugget (White Cliff)
		Triassic (?)	Ankareh (?) (Unconformity)
		Triassic	Thaynes (?) and Woodside (Probably equivalent of Dolores and Shinarump)
Paleozoic	Carboniferous	Permo-Pennsylvanian	Park City U. Wyoming
		Pennsylvanian	Weber and conformably underlying series
		Mississippian	Equivalent (?) of Madison Blue, Leadville
		Devonian	Formations under Mississippian may represent Ouray and contain Devonian strata at base
		Silurian	Not represented
		Ordovician	Ogden, and equivalents of Yule near McCoy
		Cambrian	Lodore
Proterozoic		Algonkian	Probably Algonkian, Uinta
Archeozoic		Archean	Granites Schists Gneisses

STRATIGRAPHY

NORTHEAST COLORADO

Cenozoic	Quaternary	Recent	Alluvium, river gravels, soils, etc.
		Pleistocene	Glacial deposits, alluvium, etc. Nussbaum in part
	Tertiary	Pliocene	Nussbaum in part Ogalalla
		Miocene	Arikaree
		Oligocene	White River *a* Brule *b* Chadron, Castle Rock
		Eocene	Denver, Dawson Arapahoe, Raton (?) Middle Park
Mesozoic		Upper Cretaceous	Laramie Fox Hills Pierre (and Hygiene) Niobrara Benton Dakota
		Lower Cretaceous	Purgatoire *a* Fuson *b* Lakota
		Jurassic	Morrison (some place this in Lower Cretaceous) Sundance
		Triassic	Not positively identified Some think upper part of Lykins is Triassic

Paleozoic	Carboniferous	Permo-Pennsylvanian	Lykins (and possibly Lyons)
		Pennsylvanian	Lyons, Fountain
		Mississippian	Not represented
		Devonian	Not known east of divide
		Silurian	Not known in Colorado
		Ordovician	Fremont Harding Manitou
		Cambrian	Sawatch sandstone and dolomite
Proterozoic		Algonkian	Quartzites, Coal Creek, S. Boulder, Big Thompson, etc.
Acheozoic		Archean	Granites Schists Gneisses

STRATIGRAPHY

SOUTHWEST COLORADO

Era	Period	Epoch	Formations
Cenozoic	Quaternary	Recent	Soils, alluvium
		Pleistocene	Glacial Deposits Lake and river deposits
	Tertiary	Miocene	Lake beds near Creede
		Oligocene	Probably not represented
		Eocene	Wasatch Local Unconformity Terrejon Local Unconformity Telluride Animas
Mesozoic	Cretaceous	Upper Cretaceous	McDermot Local Unconformity Kirtland Fruitland Pictured Cliffs Lewis Mesaverde Mancos (Pierre, Niobrara, Benton) Dakota Group: Dakota proper
		Lower Cretaceous	Dakota Group: Post-McElmo (probably Lakota)
	....	Jurassic	McElmo (possibly Lower Cretaceous) (Morrison, Flaming Gorge) La Plata
		Triassic	Dolores and Shinarump

Paleozoic	Carboniferous	Permian	Cutler Rico Kangaroo
		Pennsylvanian	Hermosa Molas Weber, Garfield
		Mississippian	Ouray Upper part
		Devonian	Ouray Lower part Elbert
		Silurian	Not represented
		Ordovician	Parting quartzite Yule
		Cambrian	Ignacio, Sawatch
Proterozoic		Algonkian	Needle Mt. Group: Uncompahgre, Vallecito Irving greenstone
Archeozoic		Archean	Granites Gneisses Schists

STRATIGRAPHY

SOUTHEAST COLORADO

Cenozoic	Quaternary	Recent	Alluvium, terrace gravels, soils
		Pleistocene	Glacial deposits, Alluvium, etc. Nussbaum in part
		Pliocene	Nussbaum in part Ogalalla Alamosa
		Miocene	Arikaree Santa Fe Alnwick, High Park, Florissant
		Oligocene	Possibly outliers of Castle Rock
		Eocene	Large number of local formations not exact equivalents. Huerfano, Denver, Cuchara, Poison Canyon, Arapahoe, Middle Park, Dawson Arkose, Raton (coal-bearing)
Mesozoic	Cretaceous	Upper Cretaceous	Laramie Vermejo Fox Hills Pierre Niobrara Benton Dakota
		Lower Cretaceous	Purgatoire *a* Glencairn *b* Lytle
		Jurassic	Morrison (by some placed in Lower Cretaceous) Sundance not certainly recognized
		Triassic	Not positively identified in Southeast Colorado

Paleozoic	Carboniferous	Permian	Lykins (Upper Wyoming) (Lyons possibly)
		Pennsylvanian	Lyons Hermosa Fountain
		Mississippian	Millsap
	....	Devonain	Not represented
		Silurian	Not represented
		Ordovician	Fremont Harding Manitou
		Cambrian	Sawatch
Proterozoic	....	Algonkian	Quartzites, slates, schists near Salida, etc.
Archeozoic	....	Archean	Granites, gneisses and schists

Chapter 4

METALS AND METAL MINING

GOLD, SILVER, LEAD, ZINC, COPPER

Inseparably associated with the early history of Colorado are the names of Pike, Long, Fremont, Macomb and Newberry, but the reports of their explorations reached but few and did very little to convert the western wilderness into an industrial community. It remained for the prospector to report the discovery of gold and so command the following which was to dispossess the Indian, the trapper and fur trader and lay the foundations of a great industrial commonwealth.

Mining gave Colorado her first impulse toward statehood. It called into being her first cities and towns, and but for this industry Colorado would still be only a frontier state.

In the diversity of her metal-bearing minerals Colorado has few rivals, but up to the present gold and silver have stood preeminent in her record of production. Lead, zinc and copper, though in value of output far below the precious metals, have bulked large when tonnage is considered. Iron also presents a creditable record of tonnage but so far as value of output goes has played a minor role.

The steel-hardening and improving metals, tungsten, manganese, molybdenum and vanadium are found abundantly as such metals go, and all have been developed to such an extent as to take an important part in the steel industry of the country.

Uranium, which possesses properties similar to those of the group just described, has not yet taken an important place in the steel industry. The uranium deposits have been developed mainly for the radium and vanadium contained in the carnotite ores.

Nickel, cobalt and mercury minerals have been found in the state but are not yet known in commercial quantity. Tellurium occurs native and in combination with other elements, but chiefly with gold and silver.

Selenium is recovered as a by-product from the uranium and vanadium ores of southwestern Colorado. It also occurs native in the Vulcan district of eastern Gunnison County, where there appears to be a possibility of commercial production.

Bismuth is found in many localities, but the most promising occurrences are those of the Leadville and La Plata mining districts. Some native bismuth has been shipped from Feldspar Siding on the Denver and Rio Grande Western in Fremont County. Good samples of bismuth ore have been found in Boulder, Clear Creek, Gilpin and other counties of the sulphide belt.

Antimony occurs in many mines of the sulphide belt, but no commercial deposits of antimony ores have been discovered.

Arsenic occurs as a recoverable element in the lead-silver ores of the state.

Cadmium is present in most of the zinc sulphide ores of Colorado.

Chromium ores are not known to occur in commercial quantity in the state, but good samples of chromite have been received at the office of the Colorado Geological Survey.

Titanium occurs in the form of ilmenite, titanite and titaniferous magnetite. The most important deposits are those near Cebolla Hot Springs in eastern Gunnison County.

Molybdenum occurs in great abundance in a few localities, and in promising amounts in a large number of localities. But systematic development has so far proved only a few commercial occurrences.

Nickel and Cobalt. Nickeliferous pyrrhotite has been found in several localities in the state, but the percentage of nickel is low and the deposits are small, giving no promise of commercial production. The nearest approach to a commercial deposit known in the state was that of the Gem mine near Echo, from which it is reported that some commercial ore was shipped.

Cobalt in the form of erythrite in scattered crystals has been found on Mt. Teocalli, and smaltite near Gothic in Gunnison County.

Platinum was found native in the Centennial mine, Georgetown, and one or two samples have been received from the San Juan but the exact locality was not disclosed. None of these occurrences has any apparent promise.

Tin in the form of the oxide cassiterite has been found on Devil's Head Mountain in Douglas County, but nothing approaching a commercial deposit is known. A few years ago a prospector working in the neighborhood of Arapahoe Peaks brought in a few pounds of a greisen-like rock containing scattered grains of cassiterite, but further search failed to reveal anything of promise.

Radium is an accompaniment of all uranium ores, and as such is found in the carnotite area of southwestern Colorado and in the pitchblende producing area near Central City.

GOLD, SILVER, LEAD, COPPER, ZINC

Eighteen counties have contributed in an important measure to the production of gold, silver, copper, lead and zinc. Sixteen of these counties lie in a northeast-southwest zone extending from the northern part of Boulder County to the northern part of La Plata and Montezuma counties. Two important producers, Teller and Custer, lie to the southeast of the zone and at the contiguous corners of Rio Grande, Mineral, Conejos and Archuleta, is another isolated productive area—Platoro and Summitville.

The question arises as to what geological conditions have made this zone so productive of these metals. The productive areas of Boulder, Gilpin, Clear Creek and the Montezuma area of Summit lie wholly within the pre-Cambrian crystalline rocks. The remaining producing areas of Summit, those of Lake, Eagle, Park, Pitkin, Chaffee and Gunnison are located near the contact between the pre-Cambrian and the later sedimentary rocks, mainly Paleozoic. The productive areas of the San Juan are, for the most part, related to Paleozoic sedimentary rocks and Tertiary extrusive rocks.

The country rocks of the pre-Cambrian areas are granites, gneisses and schists. Those of the Paleozoic areas are limestones, sandstones and shales. Many of the veins of the San Juan are in extrusive rocks such as rhyolites, andesites, and others.

This general mining zone may be divided into a series of rather distinct minor belts having in themselves a geological unity. The following are the principal divisions:

The Boulder-Leadville belt extending from northern Boulder County in a southwest direction to a point somewhat beyond Leadville. The north end of this belt lies wholly within the pre-Cambrian area of granites, genisses and schists. In the southern reaches beginning with Breckenridge the belt follows rather closely the line marking the boundary between pre-Cambrian and Paleozoic and later formations, and involves sedimentary formations ranging in age from Cambrian to Cretaceous.

Trending in the same general direction but farther west and south is a less continuous belt in Eagle, Pitkin and Gunnison counties. This belt is geologically similar to the Breckenridge-Ten Mile-Leadville part of the Boulder-Leadville belt. On the borders of Pitkin, Lake, Chaffee and Gunnison counties is a third belt which might be regarded as a somewhat separated southern extension of the Boulder-Leadville belt, but which is structurally and in some measure geologically distinct. Here also both pre-Cambrian and later formations are involved as country rocks.

On the border between Gunnison and Saguache counties is the rather isolated Vulcan area in pre-Cambrian crystalline rocks, but with a few isolated patches of Paleozoic strata, probably quite unrelated to the ore occurrences.

GEOLOGY OF MINERAL DEPOSITS

In this great mineral belt the diversity of country rock is a most striking feature. The pre-Cambrian complex is composed mainly of metamorphic rocks with great bodies of later, but still ancient granites. The Cambrian rocks include quartzites and slaty shales, limestones and dolomites. The Ordovician is in many places predominantly limestone but dolomite, shales, quartzite and sandstone are locally very important both in quantity and in function. The Devonian is largely limestone, but shale and quartzite occur. The Carboniferous formations are limestones, dolomitic limestones, sandstones, grits and shales. The Triassic and Jurassic bear little relation to the ore bodies. The Cretaceous rocks are mainly shales and sandstones, both of which may be calcareous. Intruded into these are many types of igneous rocks, such as granites and rhyolites, monzonites and latites, diorites and andesites, granodoirites and dacites. They take many forms such as dikes, sheets, laccoliths, chonoliths and batholiths.

Structurally, the region is one of profound folding and faulting, and intrusion of igneous rocks. In many places it is evident that there were at least two periods of folding, and two or more periods of faulting. The igneous intrusions are also of different ages.

The presence of three distinct rock types in the same fissure shows that after it was first filled, earth movements reopened it and a second intrusion of molten rock or vein matter closed it. Renewed stresses opened it a third time and a third period of filling either by molten rock or by vein matter followed. In many instances fissures filled by vein matter were reopened, widened and refilled—not infrequently by matter quite different from that of the first filling. There is much reason to believe that the process of vein opening and cementation is still in progress.

In the northeast or pre-Cambrian portion of the belt the prevailing trend of the veins is northeast, and though this feature is less regular in the areas of Paleozoic and Mesozoic rocks, northeastward trends of veins and replacement bodies of ore are strikingly frequent.

In the northeastern part of the zone faulting, igneous intrusion and mineral deposition were in part at least contemporaneous, but much mineral deposition took place after the latest intrusions.

In the Leadville-Ten Mile area the order of events appears to have been sharp folding in a northeast-southwest direction resulting in a series of thrust faults, followed by porphyry intrusions and the formation of ore bodies mainly at the contact of the Blue limestone and the white porphyry. This was followed by faulting, which in many places dislocated the ore bodies, and which as in the pre-Cambrian area, continued until very recently. But there appears to have been but one important period of ore deposition.

The Aspen district shows repeated movement along the same faults, but as in the Leadville region there was but one important period of ore deposition.

The porphyries most closely associated with the ores are similar in character throughout the great mineralized zone, and it is probable that they were roughly contemporaneous intrusions. While there is no absolute proof as to the age of these porphyries, it is considered highly probable that they belong to the earlier part of the great Laramide mountain-making period, which was followed by great outpourings of lavas, intrusions of rhyolites, andesites and other fine textured rocks.

Recent study makes it appear probable that these outcrops of porphyries and the underground occurrences are what may be termed spires, peaks and knobs of the irregular tops of batholiths.

These phenomena of folding, intrusion and faulting, vein-filling and refilling are common to the whole belt and they play the master role in the making of the ores. The heterogeneity of the country rocks has played but a minor part in the storing of the zone with ores or the determination of the character of those ores.

Mineral-charged waters from the deep seated sources from which came the molten rocks accompanied the intrusions and continued to rise long after the intrusive activity otherwise ceased. These rising solutions rose to cooler regions, lost their heat, were relieved from great pressure, were prepared to drop their load of metalliferous minerals by contact with other solutions, reacting gases, country rock or other agencies.

Gilpin, Clear Creek and Boulder Counties

This general region, and particularly the vicinity of Central City, was the goal of the first real rush of gold seekers to the Rocky Mountains, and to it the mining industry of the world is indebted for the development of much that is best in mining and metallurgical practice, whether we consider mining methods, ore dressing or the more strictly metallurgical treatment of ores. The variety and complexity of the ores and the associated gangue minerals compelled study and investigation if economic results were to be obtained, and they commanded the best effort of men of ability and resourcefulness.

The region is wholly within the pre-Cambrian complex of granites, gneisses and schists, in which the Idaho Springs formation plays the leading part. This complex has been rendered more than usually complex by the intrusions of granite, pegmatite and diorite in pre-Cambrian time; and a still greater variety of rocks, mainly of porphyritic types, in Tertiary time. These include monzonite, monzonite porphyry, granite porphyry, basalt porphyry andesites and latites.

Every form of intrusive body occurs, but the most common are dikes and lenticular masses following the structural features of the containing rocks. By far the greatest part of the intrusions preceded the deposition of the ores. Faulting occurred previous to the intrusions, at the time of the intrusions, and subsequent to them, and may still be in progress. Those faults immediately following the principal Tertiary intrusions were the most important in relation to ore-deposition.

The principal ores are those of gold and silver in the form of fissure veins, replacement bodies, and stock-works, and may be classed as pyritic ores, galena-sphalerite ores, composite ores and telluride ores. With the pyritic ores occur chalcopyrite, tennantite and locally enargite. The gold far exceeds the silver in value; and copper is a profitable product in many veins.

The galena-sphalerite deposits are much less important. They contain some chalcopyrite and the gangue minerals include quartz, calcite, barite, siderite and in one place rhodochrosite. The gold content varies widely, and though lead and zinc are generally subordinate, they are an important addition in some mines. Copper is rarely present in profitable amount.

Some areas are characterized by pyritic ores, some by the galena-sphalerite type, and on the boundaries of these areas veins may be of the pyritic type at one end, the galena-sphalerite at the other, and may carry a composite ore between, especially if there are intersections of veins of the two types.

The telluride (sylvanite) ores are found mainly between Central City and Idaho Springs and in the vicinity of Eldora. The associated minerals include cherty quartz, fluorite, roscoelite and pyrite. Free gold results from the weathering of the telluride.

Uranium ore, pitchblende, occurs with the pyritic gold and silver ores in a few mines on Quartz Hill.

The tungsten ores of the Nederland area are discussed in another place.

Copper occurs in the Evergreen mine near Apex and the ore is probably a differentiation product from monzonite.

The ores of these counties owe their origin to the Tertiary intrusives, particularly the monzonites, and were formed at moderate pressures and temperatures.

Enrichment has occurred in varying degrees, but is not a very notable feature of the region.

BOULDER COUNTY ORES

Silver-bearing veins with comparatively little galena.

1. Caribou type—Silver veins with comparatively little lead or zinc. Ore is mainly in the form of silver minerals, such as ruby silver, argentite, stephanite, native silver and gray copper, with lead and zinc sulphides in barely economic quantity, and a little copper.
2. Free gold veins containing native gold with pyrite, chalcopyrite and sulphides of lead and zinc in scarcely paying quantities.
3. Telluride veins containing the commoner tellurides of gold and silver (with the gold predominating), and free gold and ruby silver.

The relations of the two types of gold veins suggest that the telluride veins are younger than the free gold veins.

Boulder has produced a little lead and copper, but practically no zinc.

Gold,	$16,000,000.00
Silver,	8,000,000.00
Copper,	148,000.00
Lead,	347,000.00

GEORGETOWN AND IDAHO SPRINGS AREAS

The pre-Cambrian formations are granites, gneisses and schists. To the last of these belongs the Idaho Springs formation, a metasedimentary series occupying much territory within the quadrangle and north and south of it. The original rocks consisted of conglomerates, shales, sandstones and some limy beds. Pegmatites and hornblende gneiss are the oldest igneous rocks. Then followed in order quartz monzonite, granite, quartz monzonite again, quartz diorite, another granite, and lastly the Silver Plume granite, practically all of which were accompanied by pegmatites. These intrusions occur in dikes, stocks and masses of batholithic proportions.

The gold ores are typically pyritic, and the silver ores are characteristically galena-sphalerite deposits. Both types are associated with porphyry dikes and there is an evident genetic relationship between the dikes and the veins.

The Georgetown district is notably silver-bearing and the dikes are alaskite porphyry, granite porphyry, quartz monzonite porphyry, and dacite.

The Idaho Springs area is a gold-bearing district and is characterized by rocks of a more alkaline magma related to phonolite.

The silver veins contain chiefly galena, sphalerite and pyrite, in a quartz gangue derived from the country rock. The ores in their present form are believed to be depositions from descending meteoric waters, and that enrichment has taken place by leaching of the higher eroded parts of the vein and the redeposition of the minerals at greater depth. It is thought possible that some of the ores may now lie below the zone of primary mineral deposition, having been carried and deposited there by descending atmospheric waters.

The gold veins contain essentially auriferous pyrite carrying a little copper and silver, in a quartz gangue carrying also a little galena and sphalerite. The ores were deposited immediately after the intrusion of dikes accompanied by fluorspar and magmatic emanations. The mineralizing agencies were all of magmatic origin. The gold veins probably are younger than the silver veins.

The important points of deposition in the veins have been intersections and junctions, in which case precipitation has resulted from the mingling of different solutions. In other places the wall rock appears to have been the precipitating agent.

Many of the veins show different stages of opening and partial or complete refilling.

Clear Creek has had a production record of $87,000,000.00 up to 1923.

ARGENTINE TO TEN MILE

The vicinity of Argentine differs geologically from the area just described in that intrusive porphyries are not present. The ores are in veins along a zone of faulting in granite and gneiss, and are notably richer at junctions and intersections. The ores are mainly argentiferous galena, sphalerite, tetrahedrite, copper-

LISTS OF MINING DISTRICTS

BOULDER COUNTY

1. Central
2. Gold Hill
3. Grand Island (Caribou)
4. Magnolia
5. Nederland
6. Sugarloaf
7. Ward

CHAFFEE COUNTY

8. Alpine
9. Chalk Creek
10. Cleora
11. Cottonwood
12. Granite
13. La Plata (Winfield)
14. Monarch-Garfield
15. Riverside
16. Sedalia
17. South Arkansas
18. Turret

CLEAR CREEK COUNTY

19. Argentine
20. Griffith (Georgetown, Silver Plume, Queens, etc.)
21. Ideho Springs
22. Jackson (Corral, Cascade, Democrat)
23. Lincoln (Alice, Yankee)
24. Montana (Lawson, Dumont)
25. Trail
26. Upper Union (Empire)

CONEJOS COUNTY

27. Ute (Platoro)

COSTILLA COUNTY

28. Graybeck (Russell)

28a. Plomo

CUSTER COUNTY

29. Hardscrabble (Silver Cliff)
30. Spaulding

DOLORES COUNTY

31. Lone Cone (Dunton)
32. Pioneer (Rico)

EAGLE COUNTY

33. Battle Mountain (Red Cliff, Gilman)
34. Fulford
35. Holy Cross (Eagle River)

FREMONT COUNTY

36. Canon City
37. Cotopaxi
38. Currant Creek (Micanite)
39. Greenhorn (Grape Creek)
40. Red Gulch
41. Whitehorn (Menoa, Calumet)

GILPIN COUNTY

42. Central City (Central, Nevada, Gregory, Russell, Quartz Hill)
43. Independence (Perigo)
44. Pine (Kingston, Apex)

GRAND COUNTY

45. Blue Ridge
46. Corral Creek
47. Grand Lake (Wolverine)
48. Harmon
49. La Plata

GUNNISON COUNTY

50. Box Canyon
51. Cebolla (Vulcan, Domingo)
52. Cochetopa
53. Elk Mountain (Ruby)
54. Gold Brick
55. Quartz Creek
56. Rock Creek
57. Ruby
58. Tincup (Pieplant)
59. Tomichi (Whitepine)
60. White Earth

HINSDALE COUNTY

61. Galene
62. Lake (San Cristobel)
63. Park (Sherman)

HUERFANO COUNTY

64. Huerfano (Malechite)
65. La Veta

JACKSON COUNTY
(See Larimer)

JEFFERSON COUNTY

66. Evergreen (Malachite)
67. Golden

LAKE COUNTY

68. California (Leadville)
69. Harrington (Tennessee Pass)
70. Twin Lakes

LA PLATA COUNTY

71. California (Oro Fino)
72. Needle Mounteins (Florida)

LARIMER AND JACKSON COUNTIES

73. Empire (Howes Gulch)
74. Manhattan
75. Pearl
76. Steamboat Rock (Gray Rock)

MESA COUNTY

77. Uneweep

MINERAL COUNTY

78. Sunnyside (Creede)

MOFFAT COUNTY (See Routt)

MONTEZUMA COUNTY

79. East Mancos

MONTROSE COUNTY

80. Hydreulic
81. La Sal
82. Neturite (Vixen)
83. Roc Creek

OURAY COUNTY

84. Imogene Basin (Camp Bird)
85. Red Mountain
86. Sneffels
87. Uncompahgre

PARK COUNTY

88. Buckskin
89. Consolidated Montgomery
90. Halls Gulch
91. Hartsel
92. Horseshoe
93. Mosquito
94. Sacramento
95. Tarryall

PITKIN COUNTY

96. Columbia (Ashcroft)
97. Fryingpan
98. Lincoln
99. Roaring Fork (Aspen)

RIO BLANCO COUNTY

100. Coal Creek

RIO GRANDE COUNTY

101. Decatur
102. Embargo
103. Summitville

ROUTT AND MOFFAT COUNTIES

104. Copper Ridge
105. Douglas Mountein
106. Elkhorn (Three Fork, Slater)
107. Hehns Peak (Columbine)
108. Lay (Jeckrabbit)
109. Oak Creek (Red Gorge)
110. Rock Creek (Gore Ridge)
111. Skull Creek (Blue Mountain)
112. Slevonia
113. Spring Creek (Steamboat Springs)

SAGUACHE COUNTY

114. Bace Grant (Crestona)
115. Bleke (Kerber Creek)
116. Crystal Hill

SAN JUAN COUNTY

117. Animas
118. Eureka

SAN MIGUEL COUNTY

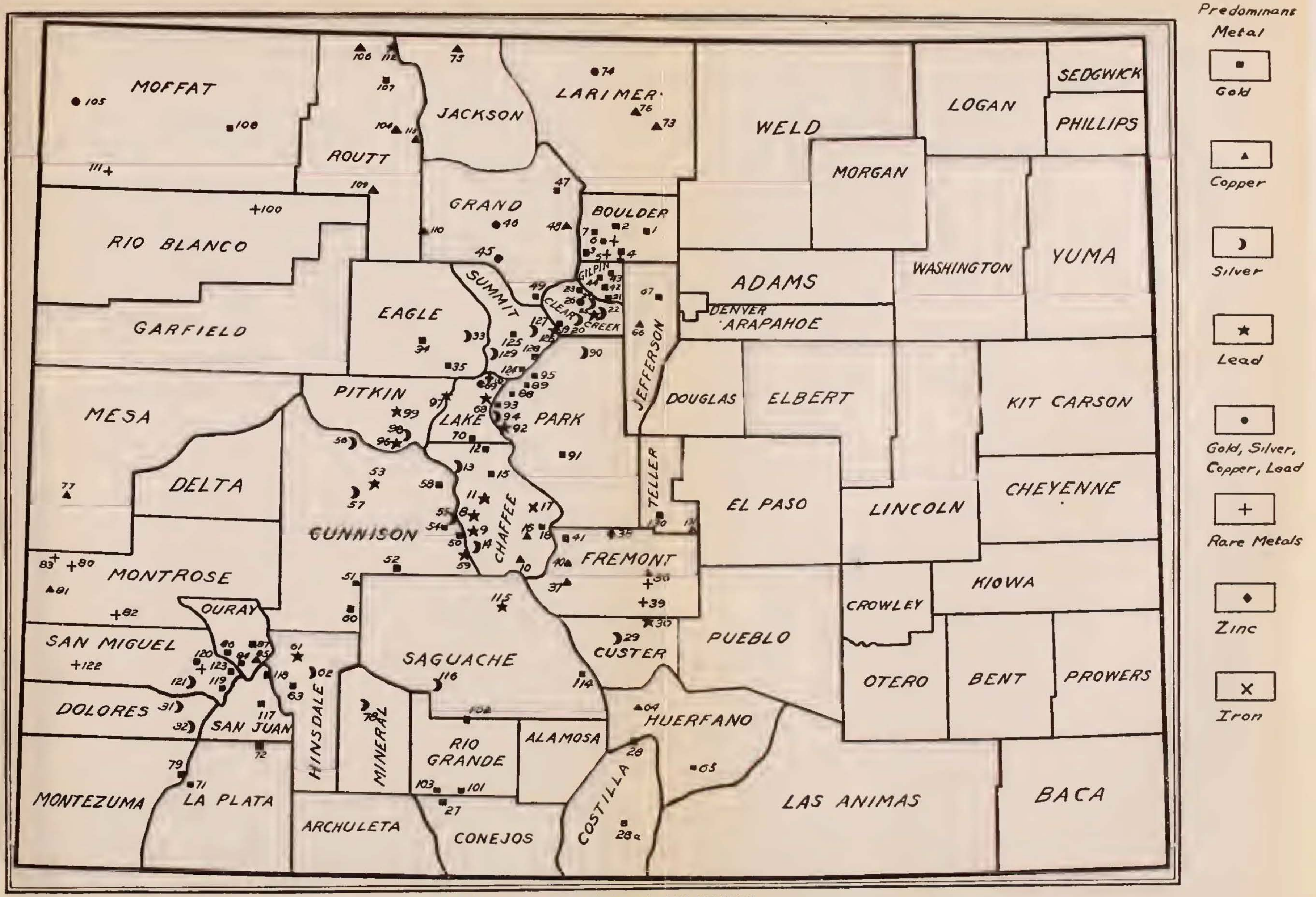
119. Iron Spring (Ophir)
120. Lower San Miguel (Placerville, Sawpit, Newmire
121. Mount Wilson
122. Snyderville (Ceder)
123. Upper San Miguel (Telluride)

SUMMIT COUNTY

124. Breckenridge (Bevan) Union, Minnesota)
125. Frisco
126. Montezuma (Snake River)
127. Peru
128. Swan River
129. Tenmile (Kokomo)

TELLER COUNTY

130. Cripple Creek
131. East Beaver



MINING DISTRICTS OF COLORADO

bearing pyrite and pyrite. The area may be said to represent a southwestward extension of the Georgetown silver area.

The Montezuma district is geologically like the Georgetown area. The country rocks are mainly the Idaho Springs formation and a series of hornblende gneisses. Pegmatite dikes are numerous. The other and later intrusives include granites, granite porphyry, aplites, and a series of porphyries later than the earliest granites but earlier than the Montezuma granite.

There are two distinct vein systems, one very strongly marked having a northeast-southwest trend, and another between northeast and north and important only where the veins intersect the stronger system.

Some of the stronger veins persist for miles and extend beyond the district.

Replacement and fissure veins predominate and rich streaks lie within lower grade ore. The gangue is mainly quartz, but siderite and barite occur.

The ores are galena, sphalerite, chalcopyrite, ruby silver, brittle silver and native silver in wire form. Some of the galena is argentiferous. Gold occurs entangled with the sulphides of silver, lead, zinc and copper. Silver and gold are the most valuable products.

Other small districts in Clear Creek, Park and Summit counties follow the same trend and the geological conditions correspond. The ores are argentiferous galena, gray copper and pyrite. The silver is the most important metal, in value, but many of the veins carry gold, and in a few lead and copper occur in paying quantities.

BRECKENRIDGE

The Breckenridge area differs from the Georgetown mainly in the presence of a series of Permo-Pennsylvanian sandstones and shales resting on the pre-Cambrian complex, and overlain by the Upper Cretaceous series including the Dakota, Benton and Niobrara, and possibly some Pierre.

Both the pre-Cambrian and the sedimentary formations are cut by monzonite, monzonite porphyry and diorite porphyry. In the sedimentary rocks the intrusive bodies are mainly sills which cross the bedding from one level to another.

The veins may be grouped as follows:

1. Zinc-lead-silver-gold series,
2. Stockworks and veins of the gold-silver-lead series,
3. Gold veins of Farncomb Hill,
4. Veins in pre-Cambrian rocks,
5. Replacements along bedding planes,
6. Gold-silver deposits in quartzite.

In the first group, the ores are galena, sphalerite and pyrite, with but little gangue. The veins are closely related to the monzonite porphyry.

The deposits of the second group occur mainly in a much fissured and veined quartz monzonite porphyry rather than in well-defined veins. Gangue matter is not abundant and the ore is mainly pyrite with varying amounts of galena and sphalerite.

The Farncomb Hill veins are in narrow fissures in the Cretaceous shales near a body of quartz monzonite porphyry. The veins were enriched gold-bearing sulphides which were later disintegrated leaving rich pockets of native gold. The monzonites were responsible for the mineralization of the Breckenridge area

Auriferous pyrite occurs in the veins in the pre-Cambrian. Free gold and quartz sometimes accompany the pyrite.

Rich placer deposits were formed in the Breckenridge area by the weathering and erosion of the mining area.

The Ten Mile District

As in many of the gold-silver mining areas of Colorado, placer mining preceded lode mining.

The pre-Cambrian complex is here overlain by the Cambrian quartzite, Ordovician limestone and quartzite, Mississippian and Pennsylvanian limestones, shales, sandstones and grits, and the Permo-Pennsylvanian sandstones, arkoses and shales.

The igneous rocks include rhyolite and a series of monzonitic porphyries similar to those of the Leadville area to the south. These are the Lincoln, Elk Mountain and Quail porphyries.

The eastern border of the area is marked by faults which bring the upper Paleozoic rocks into contact with the pre-Cambrian. The igneous rocks occur in various forms, but the sheet is by far the most common. Stocks and laccolithic intrusions are present.

The ore bodies are fissure veins and irregular replacements of limestone. The ores are prevailingly pyritic, and with the pyrite are associated galena, sphalerite antimonides and sulphides of silver, and argentiferous galena. The gangue minerals include pyrite, quartz, barite, calcite, rhodochrosite and rhodonite.

The Robinson type of ore bodies consists of narrow shoots having a northeast trend, and result from the replacement of the upper part of the Robinson limestone on either side of a series of vertical fault fissures of slight displacement.

The silver is mainly in the galena, but in richer parts of the ore it is partly in the form of sulphantimonides and sulpharsenides.

The ore of the Quail group is mainly pyrite or marcasite with argentiferous zinc blende, and argentiferous galena. Some gold occurs in the richer ores. The ores replace limestones.

Another type of ore body is marked by narrow veins following fault fissures in the sedimentary rocks, with comparatively little replacement of the country rock.

LEADVILLE DISTRICT

The sedimentary formations from the top downward are:

Pennsylvanian	Weber grits Weber shales
Mississippian and Devonian(?)	Leadville or Blue limestone
Ordovician	Parting quartzite White limestone
Cambrian	(Lower quartzite

Erosion had carved these formations into an irregular surface. Probably in early Tertiary time the White porphyry was intruded as sheets between the Weber shale and the Blue limestone and here and there between the strata of the Blue limestone. Later the Gray porphyry was intruded as sheets into Blue and White limestones and into the Lower quartzite. Then followed intense folding and faulting having a general north-south trend. Cross faults intersected these and the resulting blocks were tilted in various directions.

Ore-bearing solutions followed the faults and fissures and spread laterally along the contacts between the porphyry sheets and the sedimentary formations, replacing the limestones especially, by ores of lead, zinc, silver, gold and copper. In other places the solutions filled fissures and fractures forming veins and stock works.

Post-mineral faulting disturbed and displaced the ore and containing rocks. The ore-bearing solutions came from the same deep source as did the intruded porphyries, and were controlled in their circulation by the faults, folds, porphyry sheets and dikes They probably followed closely upon the sheet and batholithic intrusions.

The ore bodies are:

1. Contact deposits between the sedimentary formations and the intruded porphyries.
2. Blanket deposits without contact relationships.
3. Stockworks.
4. Veins or lodes.

In descending order the contact deposits are with:

The Blue limestone, the Parting quartzite, the White limestone and the Lower quartzite. The Blue limestone-White porphyry contact is the most important; the next is formed by the Gray porphyry overlying the Blue limestone resting on the Parting quartzite. Porphyry resting on White limestone has formed a good contact. The others are of less importance.

A few bodies of ore occur within the Weber grits and elsewhere without true contact relations.

Stockworks occur in the broken country rock at the intersection of faults and fissures.

Veins occur in the sedimentary rocks and the porphyries in many cases extending upward from the contact deposits.

The ores yield lead, silver, zinc, gold and copper. The ore minerals are, galena, sphalerite pyrite with some arsenic, antimony, bismuth and molybdenum. The gangue consists of jasperoid quartz. In what is known as the gold belt the ores are largely pyritic and occur in the more siliceous rocks.

This has been the greatest mining area of the state, and has produced to 1924, $428,000,000.00. In value the metals come in the following order: Silver, gold, copper, lead, zinc.

Very large bodies of ore still remain, and the period of exhaustion is far in the future.

ORDER OF EVENTS IN LEADVILLE AREA

The Paleozoic sedimentary rocks were intruded by the white and gray porphyries in late Cretaceous or early Tertiary time. The principal white porphyry intrusion is between the Weber shales and the overlying Blue Limestone, but other sheets occur within the Blue limestone. The gray porphyry forms sheets at various horizons in the Paleozoic formations. Faulting accompanied the intrusions. Then followed folding and thrust faulting on the west limbs of the folds. Normal faults formed at right angles to the thrust faults. Batholithic intrusions occurred in other parts of the great mineral belt, and it is possible that the Breece Hill stock was formed at this time.

Ore deposition followed the batholithic intrusions.

Post-mineral faulting and rhyolite extrusions were the latest events.

The reverse or thrust faults appear to have played an important part in the circulation of the mineralizing solutions.

RED CLIFF

In the Red Cliff area the pre-Cambrian complex consists of gneiss and schist with small amounts of quartzite and marble, and intrusive bodies of granite, quartz monzonite and quartz diorites.

The Paleozoic formations include the Sawatch quartzite (Cambrian), the Leadville limestone (Devonian and Mississippian), and conglomerate, sandstone, shale and limestone of Pennsylvanian age.

Intrusions of quartz monzonite porphyry, and other porphyries, diorites, and felsites probably of Tertiary age are numerous.

Faults are very numerous, but faults of great displacement are not known.

The ore bodies are fissure veins in the pre-Cambrian rocks and Sawatch quartzite, and replacement deposits in the Leadville limestone and in the Sawatch quartzite. In the fissure veins the ore is mainly in the Sawatch quartzite. The replacement ores have been much the more important and some of the bodies are very large.

The present day ores of gold, silver, lead and copper are mainly sulphides—pyrite, sphalerite, chalcopyrite and some galena. Manganese ores and manganiferous iron ores are abundant, and limonite is plentiful.

The gangue materials include jasperoid, dolomite and kaolin. The production of the earlier days was mainly from the oxidized ores.

In order of value the production of metals has stood as follows: Zinc, silver, lead, gold and copper.

Aspen and Lenado

The pre-Cambrian rocks are overlain by Paleozoic and Mesozoic sedimentary formations. In late Cretaceous and early Tertiary times sheets and dikes of monzonite porphyry and diorite porphyry were intruded and almost simultaneously there began the great Laramide mountain making movements which left the area intimately folded and closely faulted. The folding appears to have ended before the end of the Tertiary, but the stresses which were built up are still finding relief in movements along the old fault plains and probably in new faulting.

The ores are silver-lead carrying a little zinc but practically no gold.

Ore Minerals—Galena, sphalerite, polybasite, tetrahedrite and tennantite.

Gangue—Quartz, barite, dolomite.

The ores are most abundant at the intersection of steep and flatter faults. It is supposed that the mineralizing or mineral-bearing solutions rose along the steep faults and the flatter faults carried the precipitating agents—possibly hydrogen sulphide.

The ores bear much the same relation to the country rocks as do those of Leadville. They lie in the limestone and porphyry and are most abundant near the contact of the two.

ASPEN TO GUNNISON

A zone of mineralization extends southwestward from Aspen to the Ruby and Irwin districts.

Ores are at the contact of igneous rocks similar to those of the Aspen district with Cretaceous sedimentary rocks. The ore occurs as fissure veins in the network of small nearly vertical faults near the intrusion bodies. There are as a rule two sets of veins intersecting at angles of 40° to 60°.

Ores—Galena, sphalerite, pyrite carrying rather low values in silver, and a little gold.

In the Ruby district arsenopyrite, proustite and pyrargyrite occur in a gangue of quartz and calcite.

To the southwest and south of Leadville there is a broad mineralized zone following roughly the line of the Sawatch Range in which are several small mining areas such as Lackawanna Gulch, Tincup, Pitkin, Gold Brick, Alpine, Monarch-Tomichi and others. The conditions in this area are quite diverse. In the Pitkin and Gold Brick areas ores are found in both pre-Cambrian and Paleozoic rocks, in some places related to porphyry intrusions, in others not apparently so related. The Mt. Champion mine between Halfmoon and Lackawanna gulches is in quartz monzonite, but the Monarch-Tomichi ore bodies include replacements in sedimentary rocks, fault fissure fillings in sedimentary rocks, contact deposits, fissure veins, contact metamorphic deposits and ores in the pre-Cambrian crystalline rocks.

The metallic content of the ores differs widely from place to place—some districts yield mainly gold, some chiefly silver and lead, others add copper or zinc.

THE VULCAN MINING DISTRICT

The Vulcan Mining District in eastern Gunnison County is in an area of pre-Cambrian schists cut by granites. To the north and south the pre-Cambrian is covered by Tertiary volcanic rocks which are locally underlain by Mesozoic sedimentary formations. The Vulcan and Good Hope are the principal mines. The ore bodies contain large masses of copper-bearing pyrite, usually rather low grade, much native sulphur formed from the disintegration of the pyrite, native selenium as a purple, smoky powder, native gold and tellurides of gold, silver and copper. The gangue minerals include pyrite, an opaline quartz, and a spongy quartz resembling siliceous sinter.

The Good Hope vein bears evidence of much movement.

The San Juan Region

Upon the pre-Cambrian complex of granites, gneisses and schists, were laid shales, sandstones and limestones representing all the geological periods from the Cambrian to the Cretaceous except the Silurian. Accompanying the post-Cretaceous continental uplift was a general doming of the whole San Juan area followed by more emphatic local doming on the sites of the Needle, Rico and La Plata mountains.

Erosion became very active and in places the entire body of sedimentary rocks was removed and the pre-Cambrian metamorphic rocks were exposed and eroded. On this eroded surface was laid down the Telluride conglomerate of continental origin, in early Tertiary time.

Then followed a long period of great volcanic activity in which were poured out a great series of volcanic flows and tuffs separated by erosion intervals. These extrusions include the San Juan tuffs, the Silverton series of andesites, rhyolites, latites and tuffs; the Potosi series, chiefly rhyolites; the Fisher quartz latite, and the Hinsdale series of rhyolites, andesites and basalts.

Intrusive sheets and stocks of diorite and monzonite and other coarse textured and porphyritic rocks penetrate the volcanic series, and last of all came a series of basic dikes. These events were spread over much of Tertiary time.

The closing event of this part of San Juan history was the formation of an intricate network of faults and fissures which later became the vein systems, in which was deposited much of the great mineral wealth of Silverton, Telluride, Ouray, Rico, Lake City, Creede and the La Plata and Needle mountains. Besides the vein types there are extensive replacement deposits, some contact bodies and stocks.

In the Silverton district the fissure veins are the prevailing form of deposits. Most of these were formed by a single filling of fissures, but here and there the banded structure proves a discontinuous process of filling, probably caused by successive openings of the fissure. The veins are strong, and continuous and in both structure and mineral content suggest formation at a very considerable depth.

The ore minerals are pyirte, argentiferous galena, sphalerite, native gold, chalcopyrite and, in small quantity such silver ores as tetrahedrite, polybasite, argentite and ruby silver. Tellurides of gold and silver occur but are unimportant.

The principal gangue minerals are quartz, calcite, pyrite, dolomite, rhodochrosite, rhodonite, siderite, barite, fluorite and secondary feldspar. Gold, silver and lead are the chief metals, but copper and zinc are profitably recovered.

The Telluride region is in many respects similar to the Silverton, but differs from it in certain minor points. Banded veins are more common, and the lode type of deposit consisting of a series of narrow fissures separated by thin bands of country rock is a not uncommon feature. Alteration of the country rock by silicification and sericitization is quite prevalent. The Pandora vein faults a number of lesser veins containing a different mineral association and suggesting different times and conditions of vein filling. Some veins are distinctly gold-bearing, and others chiefly silver-bearing. Tellurides are rare or absent.

The ores are native gold, pyrite, galena, sphalerite, polybasite, ruby silver and chalcopyrite in gangues differing somewhat in character but composed in varying proportions of quartz, barite, fluorite, calcite and rhodochrosite.

Among the noted mines near Telluride are the Liberty Bell, Smuggler-Union and Tomboy.

The ore deposits of the Ouray district are more varied in character than those of the Telluride and Silverton areas. They may be grouped as: Silver-bearing fissure veins, gold-bearing fissure veins; replacement deposits in quartzite and replacement deposits in limestone. The most important deposits are the silver-bearing fissure veins and the replacements in quartzite. The wider fissure veins have well-defined walls limiting the ore deposition, but in many of the narrow veins the quartzite and limestone strata may show considerable replacement by ore. Sheeted lodes occur in the quartz monzonite porphyry.

The replacements in quartzite are mainly in the Dakota sandstone. Those in the limestone are commonly replacement extensions from fissure veins and from sheeted zones.

The ore minerals include native gold, gold-bearing pyrite, tetrahedrite, chalcopyrite, argentiferous galena, ruby silver and brittle silver in gangue consisting of quartz, barite, secondary silica, country rock and clay.

The productive veins of the Rico area strike northeast, and many of them were reopened after the first filling and refilled by barren vein matter. A set of northwest striking fissures was probably opened at the time of the reopening of the northeast veins, and have been the lines of later movements. The veins are clear-cut and show but little displacement. Bedded or blanket veins have been very productive.

The ore minerals are pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, argentite and ruby silver. The gangue minerals are quartz, rhodochrosite, calcite, fluorite, gypsum and barite. The ores are probably of a deeper-seated origin than most of the San Juan deposits.

In the La Plata area the sedimentary rocks have been intruded by sheets and laccoliths of porphyry, and by stocks or small batholithic bodies. These are cut by basic dikes. There are three groups of veins—one striking east and west, one striking northeast, and a third striking northwest. The first two are the strongest and most productive. The ores are believed to have been derived from the basic intrusions.

The ore minerals include: Native gold, gold and silver tellurides, argentiferous tetrahedrite, tennantite, pyrite, amalgam, stephanite, marasite, chalcopyrite, galena and sphalerite.

The gangue minerals are: Quartz calcite, rhodochrosite, dolomite, barite and fluorite. Some of the ores carry recoverable bismuth.

The principal ore deposits of the Needle Mountains are in two sets of veins at right angles to one another and striking a few degrees west of north and a few degrees north of east. Besides these there are replacement deposits along fractures or fracture zones.

The ore minerals are: Pyrite, chalcopyrite, galena and a little sphalerite in a gangue of quartz, rhodochrosite, fluorite, chalcedonic silica, and a little barite and calcite. Crustification is common, and there are two distinct periods of fissuring and ore deposition. The later fissuring followed the earlier openings. The first fissure filling consisted of cupriferous pyrite carrying gold and silver, in a siliceous gangue. The second deposition of vein matter is commonly banded.

In the Lake City district the ores occur as veins and lodes ranging from a few inches to 20 feet or more. The wider veins are banded, and branching is a very common feature. The veins cut all the rock series below the Potosi and intersect the monzonite intrusions.

The veins consist of a tetrahedrite-rhodochrosite group, a quartz-galena-sphalerite group, and a telluride group. In the first the ore minerals are galena, argentiferous tetrahedrite, sphalerite and pyrite in a gangue of quartz, rhodochrosite and more or less barite. The ore of the second group is galena, sphalerite, and a little chalcopyrite in a quartz gangue. The telluride veins contain tellurides in a fine grained quartz gangue, with some galena, sphalerite, pyrite, chalcopyrite, tetrahedrite, hinsdalite and barite.

The geological conditions about Creede are similar to those of other parts of the San Juan, but the Fisher quartz latite volcanic series is prominently developed between the Potosi and the Hinsdale flows. The Creede formation consists of fine textured, thin-bedded rhyolite tuffs overlain with coarser material chiefly breccia and conglomerate. The lake in which the Creede formation was laid down occupied a valley cut in the Potosi volcanic series.

The ore deposits are silver-lead fissure veins in rhyolite, and fractured zones of silver ore in shattered rhyolite. The veins are strong, long and deep and most of them occupy normal fault fissures, some of which have been reopened since the ore deposition.

Galena, sphalerite, chalcopyrite, pyrite, gold, silver, argentite, stephanite, anglesite, cerussite, are the ore minerals. The gangue includes amethystine quartz, chalcedony, milky quartz, barite, chlorite, adularia, rhodochrosite and other minerals.

PLATORO-SUMMITVILLE

The Platoro-Summitville mining area lies in the southeastern part of the great southwestern region of Tertiary volcanic flows and intrusive masses. It is near the headwaters of the Alamosa and Conejos rivers in Rio Grande and Conejos counties. The most important intrusive rocks are monzonite and diorite.

The veins have a northwest-southeast trend. The ore minerals include native gold, the tellurides of gold and silver, enargite, covellite, tennantite and chalcocite. The gangue is chiefly quartz resulting from the siliceous replacement of latite and other country rock. Pyrite is very abundant, and limonite formed from the oxidation of pyrite is plentiful in the oxidized portions of the veins. Faulting and folding have been important in parts of the area.

SUMMARY—SAN JUAN

The prevailing type of deposit is the fissure vein.

The commonest directions or strikes are first the northeast-southwest, and second the northwest-southeast.

The dips are steep or vertical.

The ores were deposited by rising hot waters, and followed volcanic activity.

No veins are older than the porphyries.

The accumulation of stress to the yielding point occurred at numerous times in all parts.

The veins were filled at one principal period of mineralization.

Faulting and opening of fissures occurred after the principal mineralization.

Many of these features apply equally well to the whole belt from Boulder to the San Juan, and it is very probable that the same general causes acted almost simultaneously along the belt. There is much reason to believe that the initiation of the great post-Laramie revolution developed a zone of weakness along which dislocations, foldings, intrusions and extrusions were made easy. The circulation of mineralizing solutions naturally followed these faults and fissures.

There is a very close relationship between the intrusives and the extrusives throughout the belt.

The times of intrusion and extrusion were spread over a goodly part of Tertiary time.

There are several metal mining regions outside this belt which are purely local in character and isolated. The most important of these are Cripple Creek, Silver Cliff and Rosita Hills. Others of less importance are the Spanish Peaks, and Hahns Peak.

Cripple Creek

The pre-Cambrian complex of the Cripple Creek area consists of schists and gneiss into which were intruded three types of granite, and minor bodies of gabbro and diabase.

In Tertiary time a volcanic explosion formed a great pit which was filled with a breccia composed of fragments of phonolite and related volcanic rocks and of the pre-Cambrian complex. The walls of the pit are generally steep, and in some places overhang. The breccia of the pit is cut by stock-like masses, and thick, irregular sheets of syenite and trachyphonolite, and by dikes of phonolite which also forms sheets and masses in the pre-Cambrian complex. The various Tertiary volcanic rocks are differentiation products of a single magma approaching phonolite in composition.

The ore bodies are all related to fissures, and they may be classed as lodes or veins; and irregular replacement bodies, usually in granite.

The fissures are mainly comparatively short and steep and are roughly radially arranged within and near the volcanic neck, and are most abundant in the breccia and the walls granite, but many lodes follow basic and phonolitic dikes.

The commonest lode structure is the sheeted zone consisting of rather closely spaced fractures which are as a rule very narrow. The sheeted zones rarely show evidence of displacement or faulting even at points of intersection. They were probably formed by subsidence stresses at the time of consolidation and settling of the breccia.

The principal ore mineral is calaverite, but native gold occurs in the oxidized zone. Pyrite is plentiful both in the veins and in the country rock. Galena sphalerite, tetrahedrite, stibnite and molybdenite are present in small amounts.

Gangue occurs in small volume and consists of quartz, fluorite, dolomite. The ratio of silver to gold by weight is about 1 to 10.

The ore occurs mainly in well-defined shoots ranging in thickness from a few inches to fifty feet, and in stope length from a few feet to hundreds of feet. The tenor of the ore remains constant with depth, but the number of fissures decreases.

SILVER CLIFF AND ROSITA HILLS

The Silver Cliff and Rosita Hills district is in the north central part of Custer County and is about nine miles long by four miles wide.

In Tertiary time a volcanic outbreak occurred in an area of pre-Cambrian granite and gneiss, and there followed outpourings of andesite, dacite, rhyolite and trachyte, and much fragmental material and ashes.

Ascending waters and probably fumarolic vapors formed ores in the conduit through which came the eruptions. The intrusion of a basic dike followed the formation of ores. The Bassick agglomerate occupies but a small area on the surface but extends downward in what is evidently the neck of a volcano. It consists of angular and rounded boulders several feet in diameter down to ash and dust. Andesite is the most important rock variety, but granite, gneiss, and trachyte are present.

Veins follow faults or fault zones and occur in the latest extrusive rocks. The most important ore deposit was that in the Bassick volcanic neck where a column having a cross section 20 or 30 feet by 100 feet was highly mineralized by sphalerite, galena, jamesonite, tetraherite, smithsonite, calamine, free gold, chalcopyrite and telluride of gold and silver. A little quartz was present. The ores were deposited in three or four distinct layers over boulders, and the third layer contained 60 to 120 ounces of silver and 15 to 50 ounces of gold per ton and was the principal source of value. Locally a fourth layer conisted mainly of chalcopyrite and contained much gold and silver.

Other mines contained ore of similar form and composition. Barite, calcite and quartz are common gangue minerals in the veins but not in the volcanic pipe.

The Hahns Peak region is on the slopes of the Park Range in Routt County. Paleozoic and Mesozoic sedimentary rocks rest on pre-Cambrian granites, gneisses and schists. Many bodies of acid porphyry have cut the sediments and to a less extent the pre-Cambrian, and in places have caused intense contact metamorphism.

Mineralization is rather wide-spread but no important mining area has been developed. The ores of the prospects are gold, silver, lead, copper and zinc.

Chapter 5

METALS AND METAL MINING

MANGANESE, MOLYBDENUM, TUNGSTEN, ETC.

THE STEEL-IMPROVING METALS

The rapid development of the steel industry in the last quarter of a century has brought into use and demand a series of metals of which some were but little known outside the chemical laboratories. To this group belong nickel, cobalt, manganese, tungsten, uranium, vanadium, chromium, titanium and molybdenum. Of these, Colorado can produce in abundance, manganese, tungsten, uranium, vanadium, titanium and molybdenum.

MANGANESE

The metal manganese, uncombined or unalloyed, has very few uses, but in the steel industry it has become indispensable as a means of ridding the steel of certain impurities and of adding to its hardness, tenacity and durability.

The only manganese minerals known to form ore bodies in Colorado are the two oxides pyrolusite and psilomelane, and possibly the carbonate rhodochrosite. Several others occur in small uneconomic quantities. In addition to deposits of manganese minerals by themselves, other important sources of the metal are deposits of manganiferous silver ores and manganiferous iron ores.

The true manganese ores are chiefly bedded deposits in limestone and sandstone. Both bedded and vein deposits occur in lavas and volcanic tuffs and breccias, and veins in coarse textured igneous rocks and in metamorphic rocks are known.

The massive Carboniferous limestone near the pre-Cambrian contact two miles northeast of Wellsville contains a bedded deposit of pyrolusite and psilomelane with a little manganite. Development has opened up a body of several thousand tons of ore carrying 40 per cent of metallic manganese from which some shipments have been made.

In the same formation ten miles northwest of Salida is Liberty

Hill mine containing a soft brownish-black ore composed of wad and pyrolusite which runs 33.83 per cent metallic manganese.

One of the largest deposits of manganese ore now being developed is that of the Eagle Mine a few miles east of Bonanza, where the ore occurs in vein form. This general region is known as the manganese belt.

A large deposit of manganiferous iron ore has been discovered in the Homestake or Ironclad mine at Cripple Creek. The ore averages 32.00 per cent manganese oxide and 30.00 per cent iron oxide, and the tonnage is believed to be large.

Marketable ore has been shipped from a point a short distance east of Silver Cliff. The ore is a replacement of a much weathered country rock. The deposit is reported to contain about 25,000 tons. Other deposits occur in the vicinity.

By far the most important deposits of manganiferous iron ore known in the state are those of Leadville. The ore runs 20 to 25 per cent manganese, 25 to 30 per cent iron and 10 to 15 per cent of silica, and is suitable for the manufacture of spiegeleisen, an alloy of iron and manganese used in the steel industry.

The ores are widely distributed but possibly the largest deposits are those along the eastern edge of Poverty Flat, on Carbonate Hill, in Iowa Gulch and on Iron Hill. The commonest containing rock is the Blue limestone. The ore is probably a concentration from manganiferous siderite which has locally replaced the limestone.

Much of the ore is being developed by the opening of old mine workings, and it is difficult to estimate the available tonnage, but it appears to reach into the millions.

Similar ores occur under similar conditions in the Red Cliff district, particularly in the property of the Empire Zinc Company. The ore is apparently a derivative from the manganiferous siderite. One deposit appears to have a length of 3,000 feet and a width of 1,000 feet, and contains much shipping manganese ore, and the probable tonnage may reach over a million.

Manganese and manganiferous iron ores occur on Taylor Peak on the border of Pitkin and Gunnison counties. Analyses show a range of 10.0 to 20 per cent of manganese and 25 to 30 per cent of iron. The deposits are rather remote from market and from good means of transportation, but they are of such quality as to command attention at no distant date.

In the Cebolla Valley near Powderhorn manganese ore is associated with limonite and magnetite and iron carbonate. The rocks of the district include granite, quartzite and limestone, locally capped by trachyte. The ores are mainly in the limestone and follow the bedding, but may be derived from the overlying volcanic rocks. Analyses of ore from the more highly manganiferous parts of the deposits show 41 to 44 per cent of manganese. Other deposits occur in the pre-Cambrian rocks and intrusive granites.

At many points along the Steuben Valley manganese ores occur in the great volcanic series. They are not related exclusively to one type of volcanic rock, but appear to be most abundant in the brecciated and tuffaceous forms.

There are three distinct type of ore bodies.

1. The ore occurs: In the form of a matrix bonding angular rock fragments into a breccia;

2. As bedded deposits practically free from rock matter but parallel to the flow layers; and

3. As vein cutting across the flows and bedded breccias. The veins contain the breccia ore on the vein walls, but in the center may show clean ore in a more or less continuous seam ranging from a few inches to two feet or more in thickness.

These Steuben Valley ores have been passed over rather lightly by geologists, but are worthy of investigation. The manganese content ranges from a few per cent in the breccias to that of a clean pyrolusite in the vein centers.

In the vicinity of Sapinero there are several deposits of manganese ore quite similar in character and mode of occurrence to those of Steuben Valley.

Psilomelane and some pyrolusite occur at a great many localities in western and southwestern Gunnison County and adjoining parts of Hinsdale where many claims have been staked, but so little real development work has been done that any estimate of the possibilities of the region is only a guess. The country rock consists of lava flows and breccias, and the geological conditions are similar to those of the Steuben Valley and Sapinero.

On the Lake Fork of the Gunnison near Burrows Park there is a vertical fissue vein of rhodochrosite cutting the lava flows. The upper part of the vein is weathered to pyrolusite. An average sample taken from 500 pounds of ore gave a manganese content of 41.4 per cent.

On the slopes of Hayden Mountain near "Mineral Farm" three miles from Ouray, there is a considerable deposit of manganese-iron ore consisting of a mixture of wad and limonite containing 23.0 per cent of manganese and 27.0 per cent of iron. This material was used for flux in the Ouray smelter, but if the analyses are correct it would appear to be a source of manganese for spiegeleisen or ferromanganese.

In several of the larger Rico mines rhodochrosite and manganiferous limonite carrying some gold and silver occur in considerable quantities. The manganese content ranges from 25 to 32 per cent. but the silica content is high.

On the divide between Gypsum Valley and Dry Creek Basin southwest of Placerville there is a blanket vein of pyrolusite with a little psilomelane and manganite, resting on sandstone and covered by sandy shale. Average samples of ore ran:

Manganese	43.38 per cent
Silica	8.20 per cent
Iron	trace
Sulphur	0.47 per cent
Phosphorous	0.04 per cent

and selected ore ran:

Manganese	54.75 per cent
Silica	2.79 per cent
Iron	0.46 per cent
Phosphorous	0.03 per cent
Sulphuric acid	2.69 per cent
Alumina	0.20 per cent
Lime	0.53 per cent
Magnesia	0.20 per cent
Barium oxide	5.35 per cent
Copper	0.68 per cent

Development has proved an ore body of upwards of 50,000 tons, and there is good reason to believe that further exploration will reveal much more ore of equally high quality.

Manganese and manganiferous iron ore are reported from many other localities in the state and it is probable that further development and further prospecting will prove the existence of much more commercial ore.

MOLYBDENUM

Molybdenum deposits have been reported in 24 counties of the state, and Bulletin 14 of the Colorado Geological Survey lists 61 localities in which are possibly 100 prospects, a few of which have been developed to a point which has proved their worth. Many give little promise of commercial production, but a considerable number merit further investigation.

The only commercial ore of molybdenum so far developed in Colorado is molybdenite, the sulphide. Molybdite (molybdic ochre) is a common alteration product and in the upper workings of some of the deposits may be called a commercial ore. Ilsemannite, a soluble sulphate, has been found in a few places but not in commercial quantity. Molybdenite is very widely distributed in acidic igneous rocks, such as granites, monzonites and the more acid lavas. It occurs rather commonly in metamorphic rocks such as schists and gneisses. Pegmatites should also be prospected. In general it may be said that the mountain zone of the state is prospective territory. Rich veins of molybdenite are rare, and deposits which will average more than two or three per cent of the sulphide are scarce. But under favorable conditions ore carrying between one and two per cent is profitably workable.

The California mine a few miles from Alpine in Chaffee County is a fissure vein in quartz monzonite. Molybdite is abundant in the upper workings but molybdenite is the ore of the deeper part of the vein. The associated minerals are quartz, mica and beryl. The wall rock also carries disseminated molybdenite. The ore is free from objectionable impurities.

Deposits of promise occur in the quartz monzonite of Huffman Park in the Monarch Mining District, and in the granite of the old Winfield District west of Granite. On Hope Mountain in the Twin Lakes District molybdenite occurs in many small quartz veins in fractured granite. A good grade of ore could be secured by sorting.

The most important deposit yet developed in Clear Creek County is that of the Vanadium Company of America on the slope of Red Mountain about 14 miles from Empire. The country rock is an intrusive biotite granite cut by porphyry dikes. The ore occurs mainly in small quartz veins in the shattered country rock and on the borders of porphyry dikes. The ore shipped averaged two per cent molybdenum sulphide.

Molybdenite occurs in encouraging quantity in the quartz-mica schists between Copper and Bear gulches nine miles south of Parkdale.

Several groups of claims have been located in the vicinity of Gold Hill north of Pitkin, but the amount of development is insufficient to prove the value of the deposits.

The pre-Cambrian schists in Unaweep Canyon are cut by a granite intrusion which carries some good ore.

The Lake George deposits in Park County are related to pre-Cambrian rocks cut by granite and pegmatite dikes. Development work has shown rich pockets of molybdenite in the pegmatite. Other evidences point to the possibility of commercial ore.

Near Fremont Pass on the southwest slope of Bartlett Mountain about 13 miles northeast of Leadville are the Climax deposits, by far the most important in the state and one of the largest known deposits of the world.

The country rocks include an even-grained white granite and a much fractured quartzite, cut by intrusions of granite porphyry. The molybdenite deposits are richest where the fracturing resulting from the faulting is most pronounced, and it would appear probable that the fracturing made channels for the mineralizing solutions. Much of the molybdenite is finely disseminated in veinlets of quartz in the granite.

The body of workable ore is very large and the simplest and least expensive methods of mining are in practice.

It is evident from this summary that the state is very well supplied with molybdenum ore, and the deposits best developed produce mineral of unusual purity. The tonnage of workable ore in the Climax deposits has been variously estimated, but so far development has not afforded a satisfactory basis of estimate. They are of the magnitude commonly characterized by the rather loosely used term "inexhaustible", but in this instance, if the present use and demand for the metal may be taken as indicative, the term is quite appropriate.

TUNGSTEN

All the common tungsten minerals are found in Colorado, but only ferberite and hübnerite have been produced commercially—the former in Boulder County, and the latter in the San Juan, and possibly in the Ward district of Boulder County.

The Boulder County tungsten area lies along North and Middle Boulder Creeks from Wheelmen west to Cardinal, north to Sugarloaf, and south to Beaver Creek. The area is about thirty-six square miles.

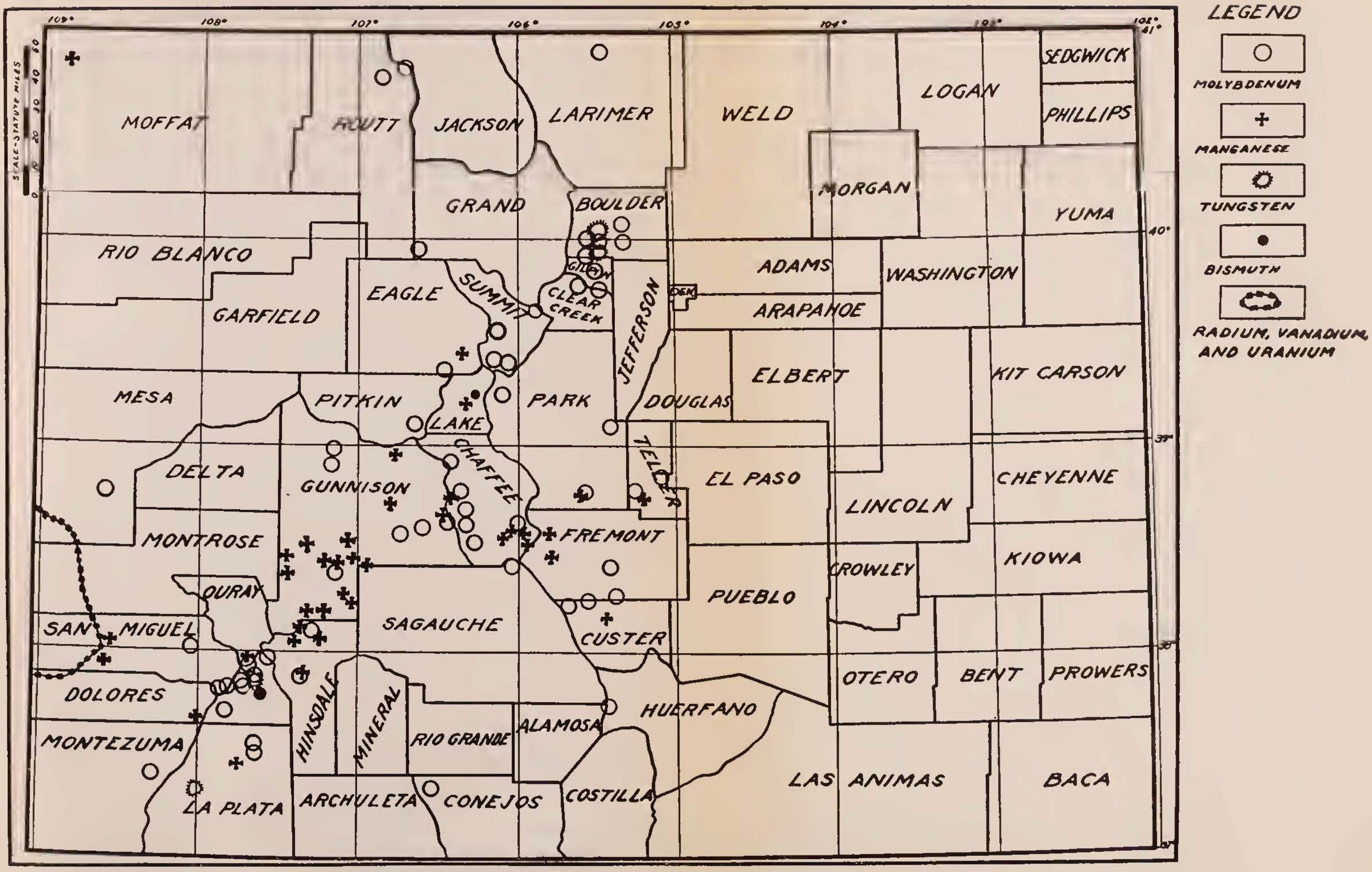
The country rocks are pre-Cambrian granites, gneisses and schists. As a rule the veins are the strongest, richest and most persistent in the granite, and weakest, leanest and most uncertain in the schists in which they are likely to be pinched out.

Many veins follow dikes of coarse and fine pegmatite. Others are associated with a fine-grained biotite granite which forms dikes and irregular masses. The veins are commonly along one wall of the dike, but occasionally they follow the middle of the dike and in some cases they leave the dike and pass into the country rock. The veins are generally rather steep. The vein filling proceeded by stages—the veins having been filled, reopened, refilled and again disturbed subsequent to any appreciable deposition of ore.

The ore occurs in three rather well-defined forms: 1. Well crystallized crusts and layers covering the surface of rock and hornstone and cementing them into a rather open breccia; 2. Massive granular ore in the wider, more open parts of the vein; 3. Highly siliceous ore in which the ferberite is in fine grains scattered through a crypto-crystalline quartz.

The distribution of the ore in the veins is very irregular and the vein area occupied by pay ore is small compared with that which must be explored in mining operations.

The area still contains much ore, but greater depth, more water and higher costs of mining have greatly reduced mining activity. The importation of foreign ores, especially Chinese, has also worked against Colorado tungsten.



MANGANESE, MOLYBDENUM, TUNGSTEN, ETC.

RADIUM, URANIUM, VANADIUM

Radium has many uses which, however, command but a small amount of the element. Perhaps the most important use is as a curative agent.

Uranium is slowly finding a place in the steel industry, but the demand is not yet very large. Salts of uranium in small quantity are used in many industries.

Vanadium is one of the steel-improving metals, and though its salts have various uses by far the greater part of the vanadium produced goes into the special steels. The oxide is used in sulphuric acid manufacture.

Carnotite, an ore of uranium and vanadium, occurs locally in an area of over 3,000 square miles lying mainly between the Colorado River on the north and McElmo Creek on the south. But outlying deposits of promise occur under similar geological conditions as far north as the Blue Mountains in Moffat County, and as far east as Meeker, and the ore may occur under the Tertiary beds of Garfield and Rio Blanco counties.

The complete geological section of the carnotite area includes pre-Cambrian granites, gneisses and schists, on which were deposited Carboniferous, Permo-Triassic, Jurassic and Cretaceous sediments. Erosion has been very active, and in a few places has cut away the entire sedimentary series and exposed the pre-Cambrian formations. In others, one, two or more of the formations remain. The McElmo formation probably of Jurassic age, is exposed along many valleys and locally over large bench-like areas. It consists of sandstones and shales, and ranges in thickness from 450 to 980 feet.

The workable deposits of carnotite are in the sandstones of the lower half of the McElmo formation, but traces of the ore have been observed in Triassic and Carboniferous formations. The ore occurs as a yellow powder impregnating the sandstones, in lenses, seams and pockets whose long dimensions usually conform to the bedding. The larger ore bodies are associated with the massive beds, and generally near their base, but sometimes in the center or at the top of these beds. The ore is commonly underlain by thin strata of greenish shale which may have influenced the circulation of waters and the deposition of the ore.

Two zones—one at 275 to 325 feet above the base, and one at 60 to 125 feet above the base of the formation—contain most of the workable ore, and are quite constant in their occurrence. In many localities two or more ore bands occur in the same sandstone bed as in the McIntyre District and Calamity Gulch.

The forms of ore bodies include: Plate-like masses and lenses of irregular outline; seams, crusts, bunches and irregular pockets of many sizes and shapes; cylindrical masses called "trees" or "logs", many of which are of very high grade ore. One of the largest bodies mined was 450 feet long, 60 feet wide and from one to four feet thick and contained 2,000 tons of ore.

In all forms of deposits impregnated sandstone is the commonest form of ore, but more or less pure carnotite may fill cavities.

Though carnotite is the most important ore there are at least a dozen more or less distinct minerals in the area. Most of them contain both uranium and vanadium, but some contain only vanadium. These are of various colors from black to red and greenish. Hewettite and metahewettite are hydrous vanadates of calcium of red color. Torbernite is a hydrous phosphate of copper and uranium of golden to green color. Vanoxite is a black hydrous oxide of vanadium, and uvanite is a hydrous vanadate of uranium.

In addition to the sandstone matrix calcite, gypsum and limonite are common associates of the carnotite.

Pure carnotite contains 59 per cent of uranium oxide and 20.5 per cent of vanadium oxide, but very little ore has been found which approached these percentages. In most of the uranium ores the percentage of vanadium oxide equalled or exceeded the uranium oxide, showing the presence of a vanadium mineral richer than carnotite.

The average tenor of ore shipped in 1919 was: Uranium oxide just over two per cent, and vanadium oxide just under four per cent.

The radium content of the ore is roughly proportional to the uranium content, but it may be a little higher or a little lower than the normal ratio as seen in pitchblende.

It is estimated that the carnotite ores mined in Colorado and Utah represent a tonnage of 45,000, and have yielded 165 grams of radium which, at the average price of $110,000.00 per gram, would give a sale value of $18,000,000.00.

The vanadium content averaged three per cent vanadium oxide or 1,350 tons, but as more than half the ore was treated for radium only, the total return from the vanadium would fall below $1,000,000.00.

Uranium was rarely marketable and as a consequence the 900 tons of the oxide added but little to the value of the ore.

The deposits are still large, and in the future will add greatly to the wealth of the state. But in 1923, the working of very rich uranium deposits in Katanga, Belgian Congo, greatly reduced the price of radium and caused the closing of most of the Colorado mines.

Pitchblende, an ore of uranium, occurs in several mines in Gilpin County but the production has been small, and very little of the ore has been used for the extraction of radium.

Roscoelite, a vanadium-bearing mica was formerly extensively mined in the vicinity of Placerville, Sawpit and Vanadium, in San Miguel County. The deposits are not now worked, but many believe there is still commercial ore remaining. The ore carried three per cent of vanadium oxide, and selected ore ran as high as three per cent of metallic vanadium.

The vanadium-bearing sandstones near Rifle are being extensively worked and have produced approximately 800,000 pounds of vanadium oxide having a sale value of $1.00 per pound. The deposits are large and the output is likely to increase.

IRON

The Taylor Peak deposits are on the high slopes of Taylor Peak in the Elk Mountains near the boundary line between Gunnison and Pitkin counties, about 18 miles from Aspen.

The rocks of the region in descending order are: Carboniferous, Devonian, Ordovician, Cambrian and pre-Cambrian. Diorite of Tertiary age has intruded the older rocks and caused contact metamorphism. Folding and faulting have made the outcrops very irregular.

The ore bodies lie in a narrow band of Carboniferous shales and limestones between the pre-Cambrian and the diorite.

The largest deposit is a replacement body in the Blue limestone and Weber formation, and is probably due to the influence of the nearby intruded diorite.

The ore is mainly a hard magnetite, and near the contact with the limestone is associated with quartz, calcite and other gangue minerals, and veinlets of iron penetrate the country rock. The deposit is about 450 feet by 750 feet, and the depth as shown by openings is such as to justify an estimate of 3,000,000 to 4,000,000 tons of ore.

Sulphur is rather high in some of the ore.

The White Pine iron ores lie on the west slope of the Sawatch Range about 10 miles north of Marshall Pass. The ores lie between quartzite and limestone near the contact of the sedimentary formations with granite, probably of pre-Cambrian age. The ores are limonitic bog iron, and replacement deposits of magnetite and limonite. The deposits are scattered along the contact zone for several hundred yards, and range in thickness from 5 to 40 feet. Those deposits within the limestone at a distance from the contact are limonite. Those along the granite contact and associated with the rhyolite are largely magnetite.

The Orient mine on the east side of the San Luis Valley in Saguache County has long been a producer of very pure iron ore, and was for many years the only producer in the state.

The deposit is a replacement of Carboniferous limestone by limonite. The ore body is very irregular in form and has been worked by open pits, and by tremendous chambers which follow the ore of shipping quality. It was considered worked out years ago, but in 1923-24 it was reopened and exploration has proved the existence of a large tonnage of commercial ore which it is hoped may equal its past production.

The titaniferous magnetites of Iron Mountain and Cebolla Creek are mentioned under titanium.

NICKEL

The Gem mine on Grape Creek, in Fremont County, is the only occurrence of nickel ore that has been developed in Colorado. The vein is in pre-Cambrian hornblende schist, is from three to four feet in width and has been opened to a depth of over 75 feet.

The ore consists of sulphides and sulphantimonides. Nickel came in at a depth of 15 to 20 feet and a shipment of 12 tons in 1882 gave returns of 12 per cent nickel, two per cent of cobalt and a workable percentage of copper. A selected shipment of one-half ton contained 34 per cent nickel and four per cent cobalt. Difficulty in following the vein led to its abandonment.

A little nickel ore was found in the hornblendic rocks near Salida, in association with copper. Some of the Leadville ores carry quantities too small to pay for recovery.

TITANIUM

On Cebolla Creek in the vicinity of the Cebolla Hot Springs are outcrops of magnetite, specular hematite, limonite and siderite, all of which are titaniferous except the siderite. The titanium dioxide ranges from nine per cent to 36 per cent, and at least a part of it is in the form of ilmenite.

Titaniferous magnetite occurs as segregations in basic intrusions on Caribou Hill, Boulder County. Most of the ore is a natural lodestone, and the content of titanium dioxide ranges from four to 37 per cent. The titanium is probably present in the form of ilmenite.

Iron Mountain is on a branch of Grape Creek, about 12 miles southwest of Canon City. The ore is magnetite carrying 10 to 15 per cent of titanium dioxide and 48 per cent of iron. The phosphorous content is low. The titanium is in very small grains of ilmenite very intimately intergrown with the magnetite. The deposit is in well-defined veins ranging from 10 to 50 feet in width. It was worked at several points as early as 1872, but the lack of shipping facilities and the difficulty of smelting caused its abandonment. There is said to be a large tonnage of ore of high iron content remaining in the deposits.

Chapter 6

THE FUTURE OF METAL MINING IN COLORADO

Few questions offer a wider range for the optimist and the pessimist than this one. And there are few questions concerning which there is less logical discussion. The optimist says that the surface of Colorado has not been scratched. The pessimist says that even the bottom has been scratched and there is nothing left. The truth lies between these extremes, and a brief review of facts bearing on the question may be of some value.

1. There is a vast area of 25,000 square miles in which the general geological conditions are favorable. Less than 5,000 square miles of this area has been geologically studied and mapped in detail, and in this 5,000 square miles actual rock exposures do not exceed 2,000 square miles. The remaining 3,000 square miles are covered by rock waste, soil, alluvium, forest and other vegetation.

2. The remaining 20,000 square miles of favorable territory is equally hidden from view by the same surface conditions.

3. The geologist can do much to interpret the geology and detailed work should be done. This should be supplemented by a thorough study with geophysical instruments which will indicate subsurface conditions in areas too deeply covered for satisfactory interpretation by the usual geological methods.

4. The absence of outcropping veins is by no means a sufficient reason for condemning an area. It would be wild folly to suppose that all ore bodies are so near the surface that visible evidence will show their presence. Ore bodies form at various depths below the surface, and are later exposed by erosion. Has erosion been so guided as to expose all ore bodies of Colorado's mountain zone? It is entirely unlikely. Geophysical instruments and methods should be applied to discover what has not been uncovered by natural processes.

5. Mining experience in all countries has proved the existence of an alternation of lean and rich depth zones in mining regions. Butte, the Mother Lode, Cripple Creek, the Lake Superior copper country, Ducktown and many other examples

might be cited. Are our mines an exception? and is the present local leanness evidence that the bottom has been reached?

6. Are Colorado methods of mining and treatment such as to make the best of low grade ores? Combination of properties into larger groups, and cooperation would greatly reduce overhead costs, and the use of geophysical instruments in underground exploration might greatly reduce the cost of development work.

A study of the records of production makes it clear that conditions other than those in the mines are in large part responsible for the present stagnation.

The conditions in Colorado justify the belief that the state has yet vast undiscovered mineral wealth, and that there is before her a long period of mining prosperity.

Within the mountain zone of the state the rock associations and the structural features are such as favor the occurrence of ores.

The surface rocks include the pre-Cambrian complex of granite, gneiss and schist, and metasedimentary rocks such as quartzites and slates. Resting on these are Paleozoic, Mesozoic and Cenozoic shales, sandstones and limestones.

At the close of Mesozoic time came a period of intense igneous activity accompanied by repeated folding, faulting, crushing and shearing.

The igneous rocks occur in the form of flows, sheets, dikes, laccoliths, batholiths and stocks, in every conceivable relationship to the other rocks and to themselves. The conditions were ideal for the formation of ore deposits, and the gold, silver, lead, zinc and copper ores were then formed.

The area just described is roughly coincident with the mountain zone of the state in which lie nearly all the metallic deposits of Colorado. Within this area every important rock type and every association of rock types has contributed to the metal production of the state. By way of example:

The pre-Cambrian granites, gneisses and schists have given the Boulder tungsten, much of the molybdenum and a goodly return of gold and silver.

The pre-Cambrian rocks and the intrusive monzonites and monzonite porphyries are largely responsible for the Boulder, Clear Creek and Gilpin gold and silver.

The sedimentary rocks of Cretaceous age and the intrusive monzonite porphyries are the ore bearing combination of Breckenridge.

Paleozoic sediments and similar intrusives in sheets, dikes and laccoliths are the country rocks of Leadville, Aspen, Ten Mile and Red Cliff.

The great extrusive series of the San Juan contain many of the richest veins.

The same extrusive series and related intrusive granitoid rocks—monzonites mainly—made Silverton a mining camp.

Intrusive bodies and Paleozoic limestones are characteristic of Rico and other San Juan mining areas.

Strictly volcanic areas within the pre-Cambrian metamorphic rocks are exemplified by Cripple Creek, Rosita and Silver Cliff.

The Mesozoic sedimentary formations unaided by igneous rocks have supplied the radium, uranium and vanadium deposits.

This area of about 25,000 square miles is largely forested up to 11,000 or 11,500 feet, above which is a comparatively small area most of which is covered by rock debris, alluvium and soil. Above timberline there is much vegetation which as effectively conceals the rock surfaces as do the forests. Rock debris, alluvium and soil, forest and smaller vegetation hide from the eye of the geologist and the prospector at least seventy-five per cent of this area favorable for ore-making, leaving only twenty-five per cent in plain sight for study.

The Hayden, King and other early geological surveys covered this great area in reconnaissance surveys but did not attempt any detailed work.

The present U. S. Geological Survey, and the Colorado Geological Survey have studied in more detail somewhat less than 5,000 square miles, or about 20 per cent of the area favorable for ore occurrence. Of the 5,000 square miles it is safe to say that actual outcrops of rock in places occupy less than 1,000 square miles.

It is true that outcrops are often so related that the geologist and the prospector are reasonably safe in assuming identity and continuity, but they have no proof. Grant that such conditions double the area of certainty, this gives only 2,000 square miles out of the 5,000 studied and only 10,000 out of the 25,000 in the zone favorable for ore deposition.

Further, do all veins and other forms of ore bodies show at the surface? In many mining districts the "blind" vein has played a star role, as in Butte, Cripple Creek, the San Juan, parts of Leadville and elsewhere.

If there are blind veins there may also be blind vein systems. It is reasonable to suppose that all the great ore deposits are marked by outcropping veins? Has erosion cut down just far enough to trim off and expose parts of the vein system of all the great ore deposits of the earth? We have great mineral deposits, the tops of which are at or near sea-level, as in the Alaska Treadwell and the Mother Lode of California. Others are topped at 10,000 to 12,000 feet above sea level, as at Cripple Creek and Leadville.

The physics and chemistry of ore formation tell us plainly that many of these deposits now exposed at the surface were formed thousands of feet below the surface. Their presence at the surface is due to the erosion of great masses of rock which once covered them.

The prospector has done excellent work wherever his eye could reach, but it cannot penetrate the covering of vegetation, alluvium, rock debris and soil and see the surface of the bedrock and its veins underneath. Much less can it pierce scores, hundreds or thousands of feet of solid rock and see the blind vein or the contact deposit lying at the surface of deeply buried igneous intrusion—the shoulder of a batholith, the side of a subsurface stock.

Other methods must be used. The prospector has done his work well, but it is now long since he has presented the state with a major discovery of any kind of ore. He has exhausted his resources.

In the last few years there have been developed several instruments which have proved of great value in geological study. They are designed to detect the presence of ore bodies and other economic deposits by the influence such bodies exert upon delicately attuned apparatus.

For example, a body of magnetic iron ore will deflect a compass needle and so make known its presence. The magnetometer records disturbances caused by magnetic bodies.

Some mineral substances conduct electricity readily, others are poor conductors. The behavior of electric currents sent through the outer part of the earth may lead to the discovery of ore bodies. Instruments used for this purpose are known as differentiometers and potentiometers.

The seismograph records earthquake shocks which pass through the earth from distant points to the instrument. Every type of rock has its peculiar power to conduct such shock waves. Some will transmit the shock readily, others with difficulty. Instruments are set, and shocks are caused by explosions. The instrument records the shock. Irregularities and peculiar records indicate variations in the material passed through. They may be due to ore bodies.

The torsion balance is a very delicately adjusted balance with one weight near the surface of the earth and the other at a certain height above it. A body of heavy ore below the surface will exert a greater influence upon the weight nearer the surface than on the one at greater distance.

The forested, soil-covered and other obscured areas should be thoroughly studied with the aid of these geophysical instruments. They are successfully used in oil geology, and have given a good account of themselves in ore finding in Canada, Sweden, and other countries.

But what of the mining areas now opened? Are they approaching exhaustion? It is very improbable that a single great mining area of Colorado is exhausted. The experience of European mining is opposed to the idea of exhaustion at such shallow depths. A few years ago the Mother Lode of California was believed to be practically exhausted at 1,800 to 2,000 feet, and a great many mines had closed down. The Kennedy in Amador County ventured a shaft 2,700 feet deep and opened very rich ore. Others followed and the Mother Lode became active from end to end. The mines had reached a lean zone, not exhaustion.

Butte has had two such experiences, but Butte is still busy. Similar things are recorded of European, Australian and South African mines. The shallow mines of Colorado do not justify the theory of exhaustion.

Such discoveries as those in the Cresson, the West Gold, the Little Annie, the London, the Red Cliff area, Mt. McClellan, and others should do much to dispel the pessimism which seems to have taken hold of mining men.

The instruments discussed are susceptible of use underground to aid in the discovery of further deposits, and will in time take the place of the expensive exploration by drift, winze and raise.

Many large bodies of workable sulphide ores of lead and zinc remain in the old workings of Leadville mines and in those of other mining districts, and large bodies of low grade ores of the precious metals were passed by in the early boom days. These should form a good starting point for a vigorous revival, as they have already done in Rico and some other districts.

With such a vast area of possible mineral ground but little known, with such shallow workings in the present camps, with a knowledge of the experience of other mining regions, there is surely much reason to predict a long period of prosperous mining in this state.

Chapter 7

FUELS

COAL

The accompanying map shows the distribution of coal in the state. The area underlain by coal is over 25,000 square miles, or nearly one-fourth of the state. The workable seams vary in thickness from three feet to 45 feet, and the gross tonnage is estimated at 372 billions, or 10% of the coal resources of the country.

But only about one-half of this vast tonnage lies within easy reach. The other half is at such a depth as to make mining unprofitable under present conditions of demand and supply.

Thirty-two counties have workable coal and no part of the state is far from a source of supply.

The mining of coal as an industry in Colorado began about 1864, but it was not until 1875 that the production reached 100,000 tons per year. The present output is over 10,000,000 tons a year, and the most important producing counties are: Las Animas, Huerfano, Weld, Routt, Fremont and Boulder.

Coal is formed from vegetable matter which grew and accumulated under conditions similar to those existing in the peat bogs of today.

As the plant matter accumulated it sank into the surface waters of the bog and was protected from subaerial (or open air) decay.

The substances contained in plant matter may be grouped as follows:

1. Cellulose is by far the largest constituent of plants. From it are formed the woody parts and the cell walls which together make up the framework of all plants.
2. Proteins have to do with the life functions.
3. Starch, sugar, fats and oils which may be called reserve plant food.
4. Waxes, resins and higher fats enter into the make-up of spore and pollen cases, cuticles, bark and coverings, all of which are primarily protective in character.
5. Exuded gums and resins may be classed as waste.

When the dead plants fall into the bog waters a process of selective decay begins. Fungi and bacteria cause decomposition and chemical change. The least resistant parts fail first and their substance is largely changed into gaseous form and escapes into the air.

Then follow in order the more resistant and in time there remains a residue containing chiefly cellulose, resins, fats, waxes and oils. This is peat, and differs chemically from the original plant matter in the much higher proportion of carbon and the lower proportion of oxygen, hydrogen and nitrogen.

These biochemical changes alone do not produce coal. If the peat is buried under a vast load of rock the chemical changes continue but the agencies producing the changes are pressure, movement and heat, and are known as dynamochemical. As in the biochemical changes, there is a progressive reduction of the less resistant and a constantly increasing proportion of the most resistant, such as resins, fats and waxes.

Depending upon the duration and the intensity of the biochemical and the dynamochemical changes, there will be formed lignite, sub-bituminous, bituminous or anthracite coal. If practically all the cellulose is removed and there remain only resinous, waxy and oily residue, the product is cannel coal.

Other things being equal, the older the coal the more advanced will be these changes and the higher will be the grade of the coal. Our Colorado coals are of Cretaceous and Tertiary age and are, therefore, much younger than the eastern coals, and we should not expect so high an average grade. In the Trinidad, the Durango, the Uinta and the Routt and Moffat counties fields and parts of other fields, changes have been accelerated by mountain-making movements which folded and compressed the rock formations and subjected the coals to pressures much higher than those which would result from depth of burial only. As a consequence, the coals of these fields are of higher grade than those of the same age on the plains areas where mountain-making movements have not affected the coals.

In the Trinidad, Yampa and Anthracite-Crested Butte areas, the coals were locally improved by the intrusion of molten igneous rocks between and adjacent to the coals seams. In the Trinidad field some of the coals were raised from sub-bituminous to high grade coking bituminous coals. Locally in the other areas of igneous intrusions the changes have gone so far as to produce high grade anthracite.

THE DENVER REGION

The Denver Region extends from the middle of El Paso County to the Wyoming line and has an area of 7,670 square miles.

The western border of the area was much affected by the earth movements which resulted in the making of the Front Range, and the coal seams and the strata containing them are locally steeply upturned, folded and faulted. These conditions have improved the quality of the coals, but have rendered mining more difficult and expensive.

A few miles east of this disturbed area the rocks and their contained coal seams lie almost horizontal but the dip of the strata from the foothills eastward has carried the coal to increasing depths below the surface, and seams which outcrop on the western margin are several hundred feet below the surface as at Leyden and other points. In the deepest areas the coals cannot now be profitably mined.

In the southeastern part of the region in Arapahoe and Elbert Counties the coal again approaches the surface and outcrops along the deeper creek valleys.

The coals of the eastern part of the region are of lower grade than those of the disturbed western part of the field.

The coal-making period was long and at no time did coal-making conditions prevail over the entire area, but small basins separated by low land areas were the rule. The basins of one part of the coal-making period would be the land areas of another. After a time the land subsided and coal-making conditions returned. As a consequence, there may be several seams more or less overlapping in one area, while in another adjoining there may be but one seam, or even an absence of workable coal. The seams range in thickness from a few inches to 16 feet.

The greater part of the coal of the Denver Region is of Laramie age, but the upper coals east of Denver are in the Arapahoe formations and are of Tertiary age.

The principal mining areas are adjacent to Colorado Springs, Denver, Golden, Boulder, Platteville, Greeley and Eaton.

THE CANON CITY COAL FIELD

The Canon City field lies south of Canon City in Fremont County, and has an area of about 50 square miles, and occupies a syncline having steep and overturn dips on the west and very gentle dips on the east. The coal-bearing formation is the Vermejo in the upper part of the Montana. In parts of the field there are as many as 16 seams, ranging in thickness from a foot or less to five or six feet. The thicker seams are mainly in the lower part of the Vermejo, but there are exceptions.

Most of the coal is of excellent quality and is especially desirable as a domestic fuel, as it is hard, clean and burns readily.

THE TRINIDAD FIELD

The Trinidad field is the northern part of the Raton Mesa Field, and lies in Las Animas and Heurfano counties. The northern end of the field is in Huerfano County and is known as the Walsenburg district. The field is about 45 miles long and 32 miles wide and has an area of 1,100 square miles. The structure is similar to that of the Canon City area—a north and south trending syncline with steep dips on the west side and gentle dips on the east side.

The greater part of the coal is in the lower part of the Vermejo formation of Montana age, but there is a little coal of lower grade in the Raton which overlies the Vermejo.

In Tertiary time the Spanish Peaks in the northwestern part of the field were the center of tremendous igneous activity, and a great many dikes were formed in radial arrangement from the peaks. Sheets or sills of molten rock were forced into and between the coal-bearing strata. Near the center of igneous activity the coal was completely destroyed. In some places the coal was changed into natural coke. In others the heat was sufficient to convert vast quantities of sub-bituminous coal into high grade bituminous and coking coals.

In parts of the field as many as 30 seams occur, and of these as many as eight may be workable. Comparatively few seams are productive over a wide area, and exploration has shown many overlappings. Some of the more noted coal groups are the Lower or Berwind-Aguilar, the Sopris and the Upper or Morley-Smith

Canon in the south and the Walsenburg-Pictou and the Upper or Sopris groups in the north.

The Trinidad coal ranges from a medium to a high grade bituminous coal affording excellent domestic and industrial fuels. Coking coal is abundant and the coke produced is of excellent quality.

THE SOUTH PARK FIELD

This field is in the eastern side of South Park, and occupies a faulted synclinal area about 20 miles long and four to five miles wide.

It is not yet certain whether the coal is in the upper part of the Montana series, as in the Canon City and Trinidad fields, or in the Laramie.

There are three principal seams separated by considerable thickness of barren strata. The seams vary widely in thickness from place to place and locally are very thick.

The greater part of the coal is bituminous and is an excellent fuel for both domestic and industrial use.

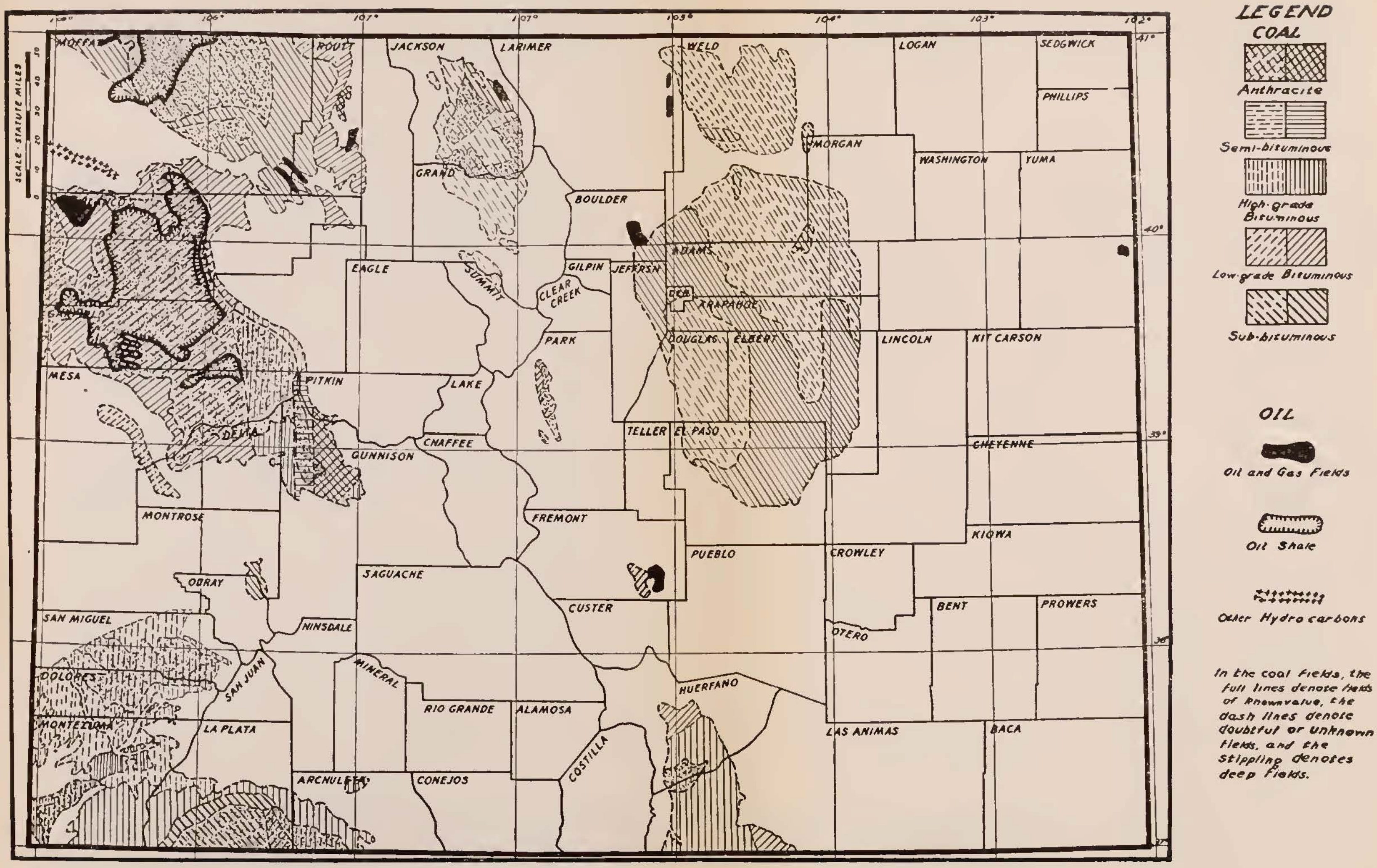
THE NORTH PARK FIELD

This field lies wholly in Jackson County and has an area of about 1,400 square miles. As yet it is very poorly served by transportation facilities and the development has been almost entirely for local use.

The coals occur in the lower part of the Coalmont formation which is probably the equivalent of the Lance of Wyoming and may be regarded as latest Cretaceous or earliest Tertiary. The upper part of the Coalmont is clearly Fort Union Tertiary. Two thin seams occur 2,000 feet above the lower and thicker seams, but are still within the Coalmont formation.

So far as development has yet gone, individual seams have not been proved over wide areas, and it is probable that, as in other fields, the coal occurs in the form of overlapping lenticular beds, some of which are known to exceed 50 feet in thickness, and the Riach seam is probably 66 feet thick.

The coal belongs to the younger group of Colorado coals, and has not advanced so far toward the bituminous grade as have those of several other fields. It is classed as sub-bituminous,



OIL AND COAL FIELDS OF COLORADO

and makes an excellent fuel for immediate and local use, but unless special storage facilities are provided it will not prove a good bunker coal.

THE ROUTT-MOFFAT AREA

THE YAMPA COAL FIELD

The great northwestern coal area of the state is commonly known as the Yampa field. It covers more than one-half of Moffat County and about one-third of Routt. The Yampa River crosses the southern part of the field and the Snake River crosses the western part. The potentially productive area is placed at 3,400 square miles.

The coals of the eastern part of the field are in the Mesaverde formation of Montana age. Farther to the west and north, Tertiary coals occur, but it is probable that Cretaceous coals underlie much of the field.

The Mesaverde coals are in three well-defined groups known as the Lower, the Middle and the Upper coal groups.

The coals range in quality from sub-bituminous to anthracite. In general, the oldest or Lower coals are the best, but locally, folding, faulting and igneous intrusions have played a part in developing the coals, and the age alone does not indicate the quality.

In the eastern part of the field there is a notable continuity of the various coal groups, and some of the seams of these are very persistent. Most of the development has been carried on from outcrops along ravines, gulches and valleys, where conditions of access and transportation were favorable, and has been very rapid since the building of the Moffat railway which has furnished an outlet not only to the larger state markets, but to those of adjacent states.

The coal compares favorably with that of the Trinidad field. But the existence of coking coal of high quality has not been proved. Anthracite occurs in an area of about 25 square miles, though the productive area will be considerably less.

Too little is known of the western part of the field to justify estimates or details as to quantity or quality of the coals. The Moffat County production is small, as might be expected on account of lack of local market and transportation facilities for reaching the outside markets, but there can be no doubt that vast quantities of high grade coal exists and that with the coming of transportation this part of the field will furnish its quota to both state and outside markets.

THE GRAND RIVER REGION (UINTA REGION)

The Grand River Region occupies parts of Gunnison, Pitkin, Delta, Mesa, Garfield, Rio Blanco and Moffat Counties in Colorado, and a large area in eastern Utah. The Colorado part covers over 6,700 square miles. The Uinta uplift separates it from the Yampa field on the north and the sharply upturned strata of the Danforth Hills and the Grand Hogback limit it on the east and northeast. The valleys of the Colorado and Gunnison lie to the south.

Structurally the area is a broad syncline having a northwest-southeast trend. The steep dips of the northeastern margin carry the coal of the central part of the basin far below the surface —beyond the present reach of economic mining. Along the southern margin the Tertiary Book Cliffs present a very abrupt face of nearly horizontal strata overlying the coal-bearing Mesa Verde. These conditions stand in the way of inexpensive development.

The active fields of the region are: The Danforth Hills and Grand Hogback, the Book Cliffs, the Grand Mesa and West Elk Mountain. In all of these there are prosperous coal mining towns.

The coal is in the Mesaverde formation and though the individual seams are not notably continuous, the coal group is very persistent, and the total thickness of coal is in many places large. At Newcastle, there are seven workable seams having a total thickness of 105 feet. The Wheeler seam is 45 feet thick. In the White River section there is 75 feet of workable coal, and along the Book Cliffs seams 15 to 21 feet thick are known.

The coals range from sub-bituminous to anthracite, and so far as the present production indicates, the bituminous coals predominate. Coking coals are found in two or three areas and an extensive plant was operated south of Glenwood Springs.

In the Anthracite-Crested Butte area igneous intrusions have changed some of the coals to Anthracite of good quality, and locally the heat has developed graphite.

The tonnage of the Grand River Region probably exceeds that of any other Colorado area.

A long, narrow strip of the Mancos formation bordering the Colorado and Gunnison rivers on the north in the vicinity of Grand Junction contains workable coal, but as yet it is but slightly developed.

THE DURANGO FIELD

This is a part of the great Durango-Gallup or San Juan River Region which extends southward into New Mexico. The Colorado part of the region, and the coal-bearing areas to the northwest in San Miguel, Dolores and Montezuma counties comprise an area of over 4,500 square miles. But the northern part of the area is not likely to be highly productive except in a few favored localities.

Coal occurs in the Mesaverde, the Laramie (?) and the Dakota formations. Of these the Mesvaerde is much the most important, both as to tonnage and quality of contained coal. Locally the Laramie (?) contains two seams of sub-bituminous coal having a thickness of 25 and 22 feet, and it is reported that the coal of one of these is of coking grade.

The Mesaverde coals are of higher grade. Locally there are as many as eight workable seams near the middle of the formation. Good coking coal is abundant and the average grade is a good bituminous coal. Many openings show seams from 20 to 30 feet thick.

The Dakota coals are in thinner seams and are not as clean as are those of the Mesaverde and Laramie formations. Very little development has been done except for local use.

The principal developments are a few miles south of Durango, Soda Springs and Carbon Junction southeast of Durango, and Lightner Creek west of Durango.

THE TONGUE MESA FIELD

This is a small field at the common corner of Gunnison, Montrose and Ouray Counties.

The coal is sub-bituminous and is mined for local use.

There are several other areas underlain by coal, but comparatively little is known as to their extent or working possibilities.

COAL MINING IN COLORADO

The average number of operating mines in Colorado is about 275, with an annual output of 10,000,000 to 11,000,000 tons.

The coal ranges in grade from sub-bituminous to anthracite, and the production by classes is usually about as follows: Bituminous 64 per cent, sub-bituminous 27 per cent, semi-bituminous 8 per cent, semi-anthracite 0.6 per cent, and anthracite 0.4 per cent.

Classified by sizes as marketed, the output is roughly as follows: Run of mine 31 per cent, lump 30 per cent, slack 30 per cent, nut 8.5 per cent and pea 0.5 per cent. But if the slack in the run of mine coal is taken into consideration the total slack would probably reach 43 per cent.

About 84 per cent of the coal is loaded at the mines for shipment, about 9 per cent is coked at the mines, 4.5 per cent is sold to the local trade and used by employes, and 2.5 per cent is used at the mines for steam and heat. The percentage yield of coke is approximately 65. About 20 per cent of the coal mined is shipped out of the state.

The room and pillar is the prevailing method of mining. In the newer mines the panel system is generally adopted. Blocks are laid out with panel entries generally parallel to the main entries, and rooms are turned off the panel entries. The size of the blocks is regulated by the local underground conditions. The panel system assures better ventilation, permits a greater extraction, and reduces the hazard of mining.

Machine mining is gaining over hand mining, but the tonnage mined by hand is still somewhat greater than that mined by machines.

Black powder and permissible explosives are used in about the ratio of two to one. A very small amount of dynamite is used.

The railways serving the coal fields are as follows:

The Trinidad-Walsenburg coal mining areas are served by the Colorado and Southern, the Denver and Rio Grande Western, and the Atchison, Topeka & Santa Fe railroads.

The Colorado Springs field is served by the D. & R. G. W. and the C. & S.

The Denver coal mining area is served by the C. & S., the Moffat, Denver & Intermountain and the U. P.

The Boulder area is served by the C. & S., the Burlington and the U. P.

The Greeley area is served by the U. P., C. & S., Great Western and Northwestern.

The Routt County fields are served by the Moffat Road.

The Canon City field is served by the S. F. and D. & R. G. W.

The Durango field is served by the D. & R. G. W.

The Grand Mesa field by the D. & R. G. W.

The Glenwood Springs field is served by the D. & R. G. W.

The Tongue Mesa field is served by the D. & R. G. W.

The North Park field is served by the Laramie, North Park and Western.

The South Park Field is served by the C. & S.

OIL AND NATURAL GAS

The theory that oil and natural gas are derived by natural distillation from the remains of plants and animals appears to be fully proved. A few of the facts bearing on the theory are: The almost universal association of oil and natural gas with rocks rich in organic remains; the natural distillation of oils from such remains may be observed in many places; the strong affinity between oil and shale or clay; and the fact that oils of the same composition as various petroleums have been produced from plant and animal substances by low temperature distillation in laboratories.

There is no evidence that oil was formed and stored in rocks before the advent of abundant life on the earth.

Experience has shown that oil and natural gas are found only where a certain combination of geological conditions exists. There must be a source rock from which the oil is derived, a reservoir rock in which it is stored and a retaining cover or seal over the reservoir to prevent the escape of the oil. The structural arrangement of this group must be such as to form a trap into which the oil from the source rock may be flushed and held.

The source rock is a rock rich in the remains of plants or animals or both. Shales are by far the commonest source rock, but shaly sandstones and clayey limestones may be source rocks. The reservoir rock may be any porous rock. Sandstones are by far the commonest, but porous limestones are common, and in a few fields closely jointed shales and even igneous rocks form reservoirs. The seal or retaining cover is most commonly a dense shale impervious to oil but not necessarily impervious to water. In addition to the more or less altered organic remains, the source rock may contain a small amount of oil distilled from animal or plant materials and stored in it at the time it was laid down on the sea floor. The pressure of a great thickness of overlying rocks, and earth movements may develop heat which will distill oil from the organic remains and add to the oil content and the earth movements may develop the structural features necessary to entrap the oil.

The agency by which the oil is flushed into the trap is ground water which in long geological ages has flowed through the rocks, has risen and fallen and in its forward and upward movements has pushed the oil ahead of it into the traps.

Too intense earth movements may so change the source rock that the oil already distilled is destroyed and the organic remains (from which under favorable conditions oil might have been distilled) are rendered valueless as a source of oil.

In the sedimentary formations of Colorado there are vast quantities of shales, some of which are rich in remains of plants and animals, while others are but poorly supplied with oil-making materials. In some places the required arrangement of source rock, reservoir and cover is found and earth movements have formed the traps and have generated heat and developed pressure enough to distill oil. Ground waters have flushed the oil into the traps and the oil fields exist.

In other places the traps are lacking, and in still others though traps were formed the oil was not generated or flushed into the traps.

COLORADO OIL FIELDS

FLORENCE FIELD

The development of the oil resources of Colorado has been very slow. The first field, and for a long time the only field in Colorado, was at Florence in Fremont County. This has been a producer since 1862, and until the discovery of oil at Boulder in 1901 was the only producer in the state. The wells are small, but many of them have produced for so long that they may be classed very properly as great wells.

Structurally the field is a syncline having rather gentle westward dips on the east side and steep eastward dips on the west.

Oil has been found at many depths, in isolated pools or reservoirs within the Pierre formation. The rock material of the reservoir appears to differ in no important respect from that above and below the oil horizons. The theory that the oil is contained in crevices is quite untenable, and the long life of the wells makes it very improbable that they are what are known as "shale" wells. It is likely that the reservoirs are formed of lenticular bodies of jointed clays.

The oil is especially rich in the lubricating fractions.

The last two years' observations have proved the existence of oil beyond the once accepted limits of the field, and have also shown that within the older area there are possibilities of years of profitable production.

BOULDER FIELD

The Boulder field may be described as an area about two miles wide and seven miles long, paralleling the foothills from the city of Boulder north to Left Hand Creek, but the production has come from several small areas totalling not more than four or five square miles. The remainder of the acreage has not been properly tested, though it is believed by a number of geologists to contain the most promising structural conditions of the field. The first producing well was drilled in 1901 and is still on the pump.

The field is one of low gas and oil pressures, and the "sands" are not marked by sharp changes in the character of the rocks penetrated by the drill. The Pierre shale in which the oil occurs is remarkably homogeneous and when drilled works up into a stiff impervious mud which would very easily "mud off" oil or gas under low pressure in the formation. There is no continuous oil sand, and the production has come from small pools at many depths. These conditions are probably responsible for the meager production and for the many areas pronounced dry and unproductive. The field is worthy of a test by the more scientific methods of development now prevailing.

The oil is high grade and the products of refining are of the best. The production has fallen to about 25 barrels per day, but it comes mainly from wells which were among the first producers in the field, and have maintained a small but dependable yield for 20 to 25 years.

For many years the city of Boulder was supplied with natural gas from a well a mile east of the city limits. But this was allowed to fail through neglect.

RANGELY FIELD

The field is in Raven Park in the extreme northwestern part of Rio Blanco County. Structurally the field is an oval anticline or dome having gentle dips to the northeast and steeper toward the south and southwest.

The first drilling was done in 1901 and 1902 and the purpose of the operators was to reach the Dakota sandstone, but as oil was found in small quantity in the Mancos the Dakota was not reached.

The smallness of the production, the lack of transportation facilities, pipe lines, refinery and local market prevented extensive development, and for a number of years the field was all but abandoned. A few years ago there was a revival of interest. A refinery was built, a number of the old wells were restored, new ones were drilled and general activity prevailed. A re-study of the geology led to an extension of development beyond the area formerly considered promising, and at the present time, (1926), the field is in better condition than ever before.

MOFFAT AND ILES DOMES

The fields are in the southeastern corner of Moffat County south of the town of Craig, the present terminal of the Denver and Salt Lake Railway. The existence of favorable structural conditions in this part of the state had been known for several years and a few shallow wells had been put down. The revival of interest in the oil possibilities of Colorado brought these two structures to notice and systematic development was undertaken in 1923, and early in 1924 the first well was brought in on the Iles dome. Since that time drilling has been very active on both domes and the daily production of the Moffat fields (Nov. 1926) was 2,710 barrels. The first wells on the Iles Dome were drilled to the

Dakota, but later operations have had the Morrison and Sundance formations as their objective, and most gratifying results are being obtained. The field gives large promise, and will justify thorough development.

The wells of these fields draw their oils from the Dakota, and lower sands.

TOW CREEK FIELD

Seepages of oil attracted attention to this area about 1900, and a few test holes were put down, but it was not until the opening of the Moffat County fields that persistent, well-backed investigation of the structure was undertaken.

The field has exceeded expectations, and promises to be an important factor in the oil production of the state. The oil is of high grade and is drawn from shale reservoirs. There is still much inviting territory undrilled.

The production (July 1927) was 1,000 barrels per day.

WELLINGTON AND FORT COLLINS STRUCTURES

The existence of the structures in this area has been known since 1908, but it was not until 1923 that effective interest resulted in the drilling of the first well which really tested the Wellington structure.

The first well opened as a gasser having an open flow of 85,000,000 cubic feet a day, but later developed into a good oil well. The drilling has been very active since the discovery well was brought in and both structures have proved productive. The gas flow and pressure vary from place to place in the fields.

The oil sand is known as the Muddy or First Dakota. The oil is of high grade, and there is a great future for the area. The production (Nov. 1926) was 5,000 barrels per day.

GAS FIELDS

Drilling on Gar Mesa in Mesa County has resulted in the discovery of what appears to be a large body of natural gas. Similar results have been obtained on the Hiawatha dome where a flow of 65,000,000 cubic feet of wet gas was obtained at 2,225 feet.

On Black Wolf Creek in Yuma County several small gas wells ranging from 1,000,000 to 6,000,000 cubic feet per day were developed in a search for oil on three small structures.

POSSIBILITIES

The oil so far developed in Colorado comes mainly from the Cretaceous formations, and drilling has been confined largely to what may be called the favored form of structure, the anticline. This is natural in the early stages of development. With the exception of a few wild cat wells and the recently drilled Iles wells, operations have been confined to the Cretaceous.

The Tertiary rocks of Colorado are all of fresh water deposition and experience has shown that they are unfavorable for oil.

Areas covered by the unconformable Tertiary formations have been avoided as it is very hard to arrive at any certain knowledge of the geological conditions and structures of the underlying formations.

From these facts it is evident that up to the present a very large part of the state has failed to attract attention. Within the areas occupied by Cretaceous there are many structures which in the older oil states would be drilled, though they are not of the favored type the closed anticline or dome. These will be drilled.

Recent developments in the western Oklahoma and Texas Panhandle fields have shown that the formerly shunned "Red Beds" may reward the venturesome driller. Southeastern Colorado has vast areas underlain by the "Red Beds" and these may be underlain by marine Pennsylvanian and Mississippian. The geological conditions appear to be not unlike those of the great Amarillo fields. The wildcat wells drilled have shown the existence of tarry sands and bitumens derived from oil. Broad structural features are favorable. These areas will be drilled.

The recent success of a well on the Hiawatha anticline in northwestern Colorado in the Tertiary area where not a sign of the Cretaceous appeared, will inevitably lead to the testing of similar structures in northwestern and northeastern Colorado.

In the southwestern part of the state are several structures involving marine Carboniferous strata which invite the oil adventurer.

In other places the marine Comanchean underlies exposed Dakota, in areas where structural conditions are favorable but where the Dakota has been broken by erosion and cannot be looked to as a possible reservoir. A selection of the best locations on these will be put to the test.

There is still much untried territory in Colorado, and her future as an oil and gas producer is by no means discouraging.

OIL SHALE

The Green River formation of Tertiary age gives promise of yielding more mineral wealth than any other formation in the state. In it there are immense volumes of shale which, when subjected to destructive distillation, yield an oil which may be fractionated and refined and made to yield a greater market return than the average petroleum from wells. These shales are called "oil shales", through they contain practically no free oil. But they do contain organic matter (chiefly plant) which, when heated to a fairly high temperature, yields an oil from which may be separated a motor fuel comparable to gasoline but more effective gallon for gallon, an illuminating oil equal to kerosene, lubricating oils of higher lubricating value than those of well oil, paraffine wax, tars, cokes and other residual products.

In the destructive distillation of the shales ammonium sulphate is given off in commercial quantity, and there are many other possible products such as chemicals, dye stuffs, medicines, perfumes, flavoring extracts, vulcanite and others.

Whether these can be produced profitably in competition with similar products from coal and well petroleum remains to be proved. The oils, wax, tars and ammonia are the outstanding products, and from these will come, in the main, the industrial returns.

The area of commercial oil shales in Colorado is over 2,000 square miles, mainly in Rio Blanco and Garfield counties, but Moffat, Mesa and Delta counties have areas of workable shale. The demand for well petroleum is rapidly increasing and the supply is as rapidly decreasing. The time is not far distant when another source of supply must be found. There is nothing in sight in America comparable to the oil shales of Colorado, Utah, and Wyoming.

The oil shales are interstratified with common clay shales and sandstones. The beds range in thickness from a few inches to many feet.

In considering questions of commercial possibilities many factors have to be taken into account, such as mining and treatment costs, labor and market. In Scotland similar shales yielding 20 gallons per ton are profitably worked, but labor is cheaper and petroleum products command a much higher price.

In the statements that follow the lower limit of profitable yield is placed at one barrel per ton, or double that found profitable in Scotland and France. The thickness of the seams is also a factor. As shale will be mined by methods similar to those used in coal mining, the American experience in coal mining may be used as a guide. In general, the minimum thickness of profitably worked bituminous coal is about two and one-half feet. It would appear safe to place the lower limit of workable beds of shale at three and one-half feet.

Locally the thickness of such workable seams in the Colorado oil shale fields exceed a total of 80 feet. An average total thickness of 20 feet of workable beds appears to be a very safe estimate. Based on these figures the Colorado oil shales will yield 56,000,000,-000 barrels of oil. If, as time goes on, it becomes possible to work shales two feet thick and yielding 20 gallons per ton, the total possible yield would be 100,000,000,000 barrels or more.

The richest shales range in color from a deep brownish mahogany to almost jet black on fresh surfaces. They are very tough and hard to break across the grain or planes of deposition, and are much lighter than common clay shale. Thin slivers burn readily.

The leaner shales are of lighter color, higher specific gravity, more brittle and are not readily kindled. The rich shales resist weathering better than the lean and as a consequence the strata project beyond the general plane of the cliffs.

The paper shales, on weathering, separate into thin papery plates parallel to the planes of deposition. They are, as a rule, rich, and the leaner shales rarely, if ever, weather to the papery form.

Thousands of experimenters have worked on the problems of utilizing the shales, and there remains no doubt that they can be made to yield industrial products of high value. The Scotch retort is now being tested at Rulison by the U. S. Bureau of Mines, and the results are confirming the findings of the more scientific private experimentators. The results of refining of the shale oils are very gratifying.

Unless the chemist and the inventor meet otherwise the problem of a future supply of motor fuel and lubricating oil, the great shale deposits of Colorado are destined to be the state's greatest mineral resource.

Chapter 8

STRUCTURAL AND INDUSTRIAL MATERIALS

BUILDING STONES, MARBLES, CLAYS, ETC.

Whether the demand be for the rugged strength of the massive granite or the artistic creations from statuary marble, it may be fully met from the stores of Colorado deposits. The great pre-Cambrian area of the Mountain zone contains a great variety and an endless supply of granite of superior strength and unexcelled beauty. The rock may be quarried in flawless blocks of any desired dimensions.

Quarries have been opened at many places along the eastern mountain front from near the Wyoming line to the Arkansas River. The more productive quarries are those tributary to the Platte and Arkansas rivers, but there is no large area in the pre-Cambrian region which could not produce an excellent granite.

West of the range near Gunnison, Aspen and other points are superior granites available whenever a market arises.

The lavas and tuffaceous rocks at Sedalia, Del Norte and in other places afford very pleasing building stones suitable for residential architecture and other uses.

The sandstones of many formations, especially the gray, pink and red rocks of the Morrison, the Lyons, Lykins and Dakota, are easily quarried, easily shaped and are suitable for a great variety of structural uses. The Lyons contains the best of flagstones. Road materials of the best wearing qualities are abundant.

Limestones are not abundant as building stones in Colorado owing to the fractured condition of most of the deposits. But near Aspen there is a marbleized limestone which should rival the famous Bedford stone from Indiana. It occurs in great quantity and may be quarried in blocks of any desired size, is easily worked and is of very pleasing color and texture.

Colorado is rich in marbles, and whenever market conditions permit any possible demand can be met whether the call is for structural, decorative or statuary marble. The deposits include stones of various colors, beautiful textures and of such structural perfection as to afford dimension blocks of any desired size.

Onyx occurs near Salida, near Steamboat Springs, near Pueblo and elsewhere.

Building sands and gravels are abundant along the rivers and smaller streams of the state.

BUILDING STONES

Of the many great deposits of excellent granites only a few have been developed to the point of production. But the state could supply the country for centuries. It is quite impossible to describe even briefly more than a few of the many fine stones from which the architect may choose.

The Texas Creek quarries yield both gray and red granites. The gray is a medium textured, light gray biotite granite of very uniform composition, color and strength. In parts of the quarry there is a suggestion of mottling which adds to the attractiveness. The usual tests show that it possesses all the qualities of a high grade architectural stone. The red granite is similar in composition, strength, permanence of color, and workability. But there is a distinct gneissoid arrangement of the minerals giving the stone a pleasing directional structure. The average texture is a little coarser.

The Gunnison or Aberdeen gray granite was used in the Capitol, Denver. It is a dense, rather dark bluish gray rock of medium texture and a very slightly gneissoid structure. In composition it resembles a monzonite or granodiorite. The minerals contained are quartz, orthoclase, plagioclase, hornblende, augite and biotite. The rock cuts well, takes a good polish, and possesses all the strength required.

The Platte Canyon red granite is one of the most extensively used granites of the State, and has found a good market in several neighboring states. It is a coarse, massive rock composed of orthoclase, quartz, biotite and a little hornblende. As may be expected, it stands up well under all the usual tests, and in actual service.

The Salida granite (really a monzonite) is a bluish-gray even textured rock composed of feldspars, biotite, hornblende and a sprinkling of augite. The rock is eminently suitable for monuments, on account of its fine working qualities and durability. It is a rock of unusual strength, and would serve any architectural purpose.

The Cotopaxi gray granite is extensively used for monuments, for which it is well suited. The rock is a biotite granite carrying a small amount of hornblende. It chisels well, takes a fine polish and appears to be very durable.

The pink Cotopaxi is quarried a short distance from the gray, and has many of the qualities of the gray stone. It is a durable rock, cuts well, and has ample strength for all architectural purposes.

The Silver Plume granite is an outstanding stone and has made a well-deserved place for itself. It is a medium textured gray rock composed of microcline, orthoclase and plagioclase. Biotite and a little muscovite are present.

The White Star granite from the Platte Canyon is a beautiful nearly white granite of fine texture, low porosity and absorption and excellent working qualities. There is just enough color in the form of hematite dots to give it a lively and pleasing color tone. It has ample strength for all purposes, and weathers remarkably well.

Beautiful monzonites in every respect suitable for architectural use occur very abundantly in the great metal mining belt from Boulder County to the San Juan. Exceptionally attractive deposits occur near Rowena in Boulder County; west of Empire and at other points in the Georgetown area; northeast of Garfield in the Monarch-Tomichi area; in great abundance in the Collegiate Range, especially on Mt. Princeton, and in the San Juan especially near Silverton.

Similar rocks occur in northeastern Colorado along the Front Range. From one of these deposits near Fort Collins came the stone used in the U. S. Mint Building, in Denver.

The Castle Rock lava is a lightweight, easily quarried, easily shaped stone of pleasing appearance. It is suitable for all architectural uses in small buildings, and will stand up well under ordinary use.

The Del Norte lava is a light pinkish gray rock speckled with black biotite. It is a fragmental rock of high porosity and high absorption. It is suitable for structures where the load to be carried is small.

It is easily dressed and retains its form and color well.

The Fort Collins sandstone is a very workable stone of fine, brownish-red color, great durability and much more than average strength. It is easily quarried, readily shaped by any of the usual methods—saw, planer or lathe.

It is very suitable to our Colorado landscapes, and will compare favorably with the best sandstones in the country.

The St. Vrain sandstone is in reality a quartzite of coarse sand cemented with silica, with enough iron oxide present to give it a pink color. It is a very durable stone of great strength and is well suited to all purposes where fine dressing is not required. It cannot be economically sawed or smooth-dressed.

The Lyons sandstone is a quartzitic rock very similar to the St. Vrain. The quarries yield quite a variety of color tones, and some beautifully mottled rock. It is very durable, keeps its color and for certain forms of construction cannot be excelled. It makes excellent flagging.

The Boulder sandstone is essentially the same rock.

The Steamboat Springs sandstone, the Turkey Creek sandstone, and many others are excellent building stones particularly suitable for small and medium size buildings and other structural uses.

The most promising limestone in the state is probably a marbleized bluish gray, medium textured rock which was once quarried a short distance south of Aspen. It is an easily worked, durable, handsome rock which can be obtained in any desired sizes, and should serve all the purposes to which the Bedford stone of Indiana is put.

Numerous deposits of travertine occur along the Arkansas River and elsewhere in the State. A very large deposit near Howard is being operated and a fine quality of brownish gray banded stone is being marketed. The rock takes a beautiful surface finish and the banding and distribution of pores give it a very attractive appearance.

MARBLE

In the mountain-making processes which have many times tortured the rocks of Colorado the limestones have been subjected to folding and compression, and occasionally have been raised to high temperature by the intrusion of molten igneous masses or the outpouring of lavas. In many places by these means the common, dull gray unattractive limestone was converted into the beautiful white and mottled marbles which occur so abundantly in the mountains of Colorado, inviting the sculptor and the architect to practice their creative arts, to envisage the angel, the lily, and the temple in the lifeless stone, and by the magic of hammer and chisel call them forth to delight, instruct and uplift.

Far beyond any present or immediate future need are the vast stores of marble, largely concealed from view, but here and there outcropping on the mountain sides and in the canyon walls.

The only marble deposit of Colorado that has been worked extensively is that on Yule Creek, four miles from the town of Marble, Gunnison County. The deposit is of very great size but prospecting has not gone far enough to prove its extent. As to the quality of the marble, the following varieties are recognized: First, a pure white marble which occurs in textures ranging from the finest statuary marble closely resembling the Pentelic of Greece and the Carrara of Italy, to a rather coarse textured and cleavage-mottled variety of very high crushing strength, admirably suited for architectural purposes. The white marble occurs in such continuous and massive deposits that blocks of any desired size can be obtained; Second, a white marble delicately veined with golden yellow and ranging in texture as does the white; Third, a white product with dark clouding which also occurs in a variety of textures; Fourth, a dove-colored marble of very fine texture and of excellent sculptural qualities; Fifth, a blue gray marble more or less mottled with darker streaks of the same color. Any of these marbles can be secured in any desired quantity, but the first three are regarded as the staple products.

The working qualities of the Yule marble have been demonstrated in every possible way and the results have proved it to be an exceptionally high grade product, whether it is used in architecture, monumental work or statuary.

At a short distance from the Colorado Yule deposits at a point higher up on the mountains, there are many varieties of mottled marbles. These are developed from impure limestones and present in mottlings different shades of green, yellow, red, purple, pink, brown and black. A good serpentine marble also occurs. The deposits have not been prospected sufficiently to prove their extent, but there is good reason to believe that a very large quantity of high-grade decorative stone is available.

On West Castle Creek in Pitkin County there is a large deposit of marble which has been developed to a very limited extent by the stripping of the surface and a small amount of channeling. The work has shown the existence of two deposits of distinctly different rock. One is a dark blue marble which on polished surfaces has an almost black color tone. The other is a white marble comparable to the Yule Marble. Various estimates have been made as to the extent of these deposits, but there has not been sufficient development work to justify any statements except that they are of great size. A certain amount of core drilling indicates that the quality is constant.

Near this deposit is a very attractive brown to red mottled marble of excellent quality for decorative work.

A few miles northeast of the city of Salida, Chaffee County, there are deposits of white marble which have been opened to a limited extent, more by way of sampling than for commercial purposes. The marble is of excellent quality and includes a pure white and faintly yellowish variety, and a mottled or veined variety.

In the eastern part of Gunnison County, marbles are found in the Tomichi district on Stella Mountain to the west of Tomichi Creek; Porcupine Ridge, West Point and Lake Hill, near the mining camps of White Pine and North Star east of Tomichi Creek.

On the eastern side of the Continental Divide in Chaffee County, marble deposits occur near the mining towns of Monarch and Garfield in Taylor Gulch, and on Missouri Hill, north and east of the town of Garfield. These deposits are undeveloped, but some have been cut in mining operations and, while the volume of the rock is not known, it is believed to be large. The varieties include pure white marbles of a variety of textures, blue marble of rather fine texture, and graphitic black marble of fine to medium texture. There is also a mottled serpentinous marble and a variety carrying considerable olivine in small grains. Ophicalcite occurs in small quantity. A number of these deposits are near enough to transportation to justify investigation with a view to development.

A few miles west of Pueblo an onyx quarry was opened up to secure decorative material for the interior of the Colorado Capitol Building in Denver. The onyx varies in color from a dark red to pink, brown, yellow and gray. It is not regularly banded as is the Mexican onyx, and it is probable that the distribution of color is not due to deposition but rather to weathering and changes long subsequent to deposition.

In the western border of Pueblo County not far from the Beulah, a quarry was opened some years ago in a deposit of excellent white marble of fairly coarse texture.

On Twin Mountain, five miles northwest of Canon City, in Fremont County, occurs a deposit of lavender colored marble, veined and clouded by deep red and a warm yellow very similar to the Sienna marbles of Europe. The deposit contains "many thick bodies of colored marbles of the finest quality. The most extensive occur in a series of benches or low spurs between gulches along the eastern base of the mountain." The deposit has a thickness of fifty to one hundred feet and extends along the base of the mountain for a distance of upward of two miles. Analyses show that the marble contains one-half the magnesium carbonate of a normal dolomite. This fact accounts for the superior hardness and good polishing qualities, and the excellent durability. It is harder and tougher than ordinary marbles. It is sound and flawless near the surface. The beds are one to several feet in thickness, and joints are far enough apart to afford large blocks. The quarried product can be let down by gravity to cars in the valley. No other deposits of this variety is known in Colorado. It can be safely said that the product compares with the most highly prized European marbles.

Many other occurrences of marble are reported but very little is known as to the size of the deposits or the quality of the stone. Among these the following counties are represented: Boulder, Fremont and Larimer.

Northeast of Villa Grove on the east side of the north end of San Luis valley, the Mississippian limestones have been folded, faulted and compressed until a high degree of metamorphism has resulted in the formation of beautifully colored marbles. Red and black are the dominant colors, but gray, pink, yellowish pink, brown and green occur. The deposits appear from present development to be large, and slabs 15 feet square of good marble can be cut. Smaller material suitable for mosaic and other decorative uses is abundant.

CLAYS

The molding of clay into useful forms, ornaments and objects of worship is believed to have been the earliest handicraft of the human race. The discovery that fire would give greater strength, durability and beauty to the molded forms was a further step in the development of the plastic arts which have contributed so much to man's comfort, development, profit and pleasure.

Clays are products of rock weathering and decay. Some clays lie on the surface of the rocks from which they were formed. The parent rock may contain twenty or more of the chemical elements, but the pure clay formed from it will contain only four —aluminum, silicon, oxygen and hydrogen combined in the form of kaolin. It is a residue resulting from the chemical and physical changes which the rock has undergone by exposure to the atmosphere. Such clay is known as residual clay.

When these products of rock decay are carried by water, wind and gravity and deposited in other places they are called transported or sedimentary clays. They commonly contain many mineral and rock fragments together with a varying percentage of kaolin or minerals of the kaolin group.

Sedimentary clays are by far the most common, and many rock formations are composed almost entirely of clay. East of the foothills of the Front Range in the neighborhood of Denver the Benton, Niobrara, Pierre and Fox Hills formations contain a total thickness of over 9,000 feet of sedimentary clays. Equal volumes occur in the Mancos, Mesaverde and Lewis, in the west ern part of the state.

From the economic or industrial standpoint, clay is fine grained mineral matter which when moistened may be molded and baked into useful forms. The great variety of rocks occuring in Colorado and the diversity of climatic conditions have made Colorado wonderfully rich in clays. From these may be made the common building brick, the paver, the heat-resisting fire-brick, the massive building blocks, the artistic vase and the delicate translucent porcelain.

Some of the more important types of economic clays are as follows:

Brick clay suitable for the making of brick, tile and terra cotta, is found in every county in the state, and many local plants supply the building trade. In eastern and western Colorado the Cretaceous and Tertiary formations are inexhaustible sources of this most used clay. In the mountain area various sedimentary formations including recent alluvial deposits more than meet the demand.

East of the range, high grade fire clays are very abundant in the Dakota, the Purgatoire and the Dawson formations. Fire clay has been reported from the Laramie formation but it has not been developed. The Dakota and Dawson fire clays are extensively worked in eastern Colorado for the supply of operators in Denver, Colorado Springs and Pueblo.

Very little demand for fire clay products has developed in the west side of the state. But good fire clays are known in the Dakota group and the Jurassic. Search would undoubtedly lead to the discovery of fire clays in other formations.

The products of Colorado fire clays are unexcelled.

Earthenware clays suitable for the manufacture of commoner glazed and unglazed earthenware, occur abundantly, but they are not yet extensively developed.

Pottery clay is any clay suitable for pottery manufacture. That pottery clays of excellent quality occur in the state has long been known, and the beautiful Van Briggle art pottery proves the excellence of some of these materials.

Kaolin or china clay of very high quality occurs in the Dakota, and is used in the Coors porcelain plant at Golden. Residual kaolin occurs in several localities.

The clay products produced in the state include all kinds of structural materials, all kinds of fire clay products, floor, wall and roofing tile, terra cotta, artificial stone, porcelain, art pottery and many others.

It is highly probable that any industrial clay desired could be found in the state.

Other mineral substances used in the ceramic arts are: Feldspar, sillimanite, andalusite and cyanite, bentonite, fluorspar, silica, and beryl.

Feldspar is an important constituent of practically all white ware bodies, porcelains (china), tile for walls, floors and ornamental use, glazes, enamels; opalescent glass, plate, window and bottle glass, and to a limited extent in the manufacture of Portland cement.

Feldspar occurs very abundantly in pegmatite dikes in the pre-Cambrian areas of Colorado. Orthoclase and microcline are by far the commonest, and numerous deposits are of such size as to justify development. Feldspar, both crude and ground, is shipped to the middle eastern markets mainly for the ceramic industries, in which they are used as a solvent or flux for the clay bodies, and as a means of controlling the process of vitrification. It is also used in the manufacture of glazes, enamels, opalescent glass and many other products,

Sillimanite is much in demand for refractory porcelains such as spark plugs and insulators. It occurs abundantly in the pre-Cambrian schists and gneisses in several parts of the pre-Cambrian area, but as yet no attempt has been made to concentrate and market the mineral. Other aluminum silicates such as andalusite and cyanite could be used in the same way. They are found in Colorado but are not yet known in commercial quantities.

Fluorspar is used in glass and enamel ware but as much the larger part is used as flux in the steel industry it will be considered more fully in that connection.

Bentonite is a name applied to clay-like mineral substances differing quite widely in chemical composition, but possessing similar physical properties such as high plasticity, high absorption, and very fine texture. They differ quite widely in colloidal content, and this fact determines some of the many uses of the material.

Though not yet extensively used in ceramics, certain of its properties suggest possibilities which are attracting much attention.

Bentonite is found in great abundance in the Mesozoic formations of western Colorado, and to a lesser extent in the Cretaceous formations of eastern Colorado.

It is used as a paper filler, a filtering agent, decoloring agent, an absorbent in dewatering liquids, a constituent of soaps, paints, insulating materials, a water-softening agent, a bonding material in certain ceramic products, medicinal dressings and in many other ways.

CEMENTS

Natural rock cement is a hydraulic cement formed by burning calcareous rocks to a clinker and grinding it to a fine powder. This powder when moistened with water will "set" or harden into a stone-like mass. The raw materials for natural rock cement are clay marls, and impure limestones containing clay and silica.

The tendency at the present time is to apply strictly scientific methods to the making of cements and to apportion the raw materials in just those proportions in which they will unite chemically to form the strongest bonding material possible, and not risk the natural mixtures of these parts. As a consequence, very little natural rock cement is now made. However, there is in Colorado an abundance of suitable raw materials for natural rock cement.

Portland cement is a hydraulic cement made from limestone and clay apportioned in exactly the ratios to produce well-known compounds of great bonding strength and durability. The mixture is ground and burned to a clinker and then reduced to a powder.

Limestones and clays suitable for the manufacture of Portland cement occur in great abundance on both sides of the range. The three plants now operating are using both limestone and clay from the Niobrara formation which fronts the foothills from the Wyoming line to the Arkansas River, and is widely distributed both south and north of the river in southeastern Colorado.

In the mountain area and west of the range the Pennsylvanian formations contain quantities of high grade limestone and shales far in excess of any probable demand for cement manufacture. Other formations of Ordovician and Cretaceous age also contain excellent raw materials, in abundance.

LIME

The limestones mentioned as cement materials are equally well suited to the making of quicklime. They are widely distributed near to transportation and to centers of demand.

There appears to be no good reason why Colorado should not produce her own lime and become an exporter rather than an importer of this much used building material. Much of the limestone of the Niobrara formation contains some magnesium carbonate but the prejudice against such limestones as lime-makers is fast disappearing in the face of abundant proof that a magnesian limestone will make quite as good lime as the pure calcium carbonate rock.

Lime and limestone are extensively used as a conditioning agent for many kinds of soils, and especially for improving the socalled sour soils.

A pure limestone lime is much used in the refining of sugar.

GYPSUM

Gypsum is the raw material from which a great variety of building material is made. Gypsum products are also used in many other branches of industry.

Colorado is extremely rich in this mineral which occurs in the "Red Beds" formations at intervals along the Front Range, at many places within the mountain area, and in great abundance in the Pennsylvanian and Permian formations in the western part of the state. The quality is exceptionally high and the supply is inexhaustible. Two well-equipped factories produce a wide range of gypsum products, especially for the building trades.

Some of the principal products are: Gypsum plaster, a substitute for lime for all inside use, stucco for exterior use, partition blocks, wall-board, roofing slabs, plaster of Paris for finishing coats, molding, patternmaking and other uses. Hard finish plasters (Keene's and Mack's cements) are specially prepared by additional calcining and the addition of hardening substances.

Ground gypsum, known as land plaster, is a soil conditioning agent. Fine textured and delicately colored massive gypsum known as alabaster is used for sculpturing.

The transparent crystallized gypsum, selenite, has various uses in optical instruments.

BITUMEN, ASPHALT, TAR SANDS

These solid and semi-solid hydrocarbons are residues derived from petroleum by the evaporation of the lighter oils and the more or less complete oxidation of the heavier fractions. The physical and chemical properties of the bitumens depend upon the character of the parent oil, the agencies of change and the conditions under which these agencies operated.

From the nature of their origin it is evident that they will grade into one another both physically and chemically, and forms widely different are found in the same area and from the same source.

Three types are recognized in western Colorado. These are: The Grahamite of Grand County, the Gilsonite of Rio Blanco and Garfield counties, and the tar or asphalt sands occurring in several western counties.

The first two occurs as vein fillings formed by the welling of petroleum into fissures and the evaporation of the lighter fractions of the oil, and other changes. The third is the heavy residue resulting from the exposure and weathering of an oil-saturated sand. These all occur in commerical quantities. Grahamite has been mined in Middle Park and Gilsonite veins have been opened in Rio Blanco County near the Utah line. A softer hydrocarbon was mined for several years near the head of Parachute Creek in Garfield County. The tar sands are worthy of study also, as a possible road-making material.

ABRASIVES

Under the general term abrasives are included all mineral substances used for grinding, polishing and burnishing, and scouring. Many mineral substances are used for these purposes, and as they are very widely distributed in the industrial states only very special kinds or qualities of abrasives can be profitably shipped very far.

Sandstones suitable for grindstones and pulpstones occur in the Dakota, the Morrison and other formations, and a limited development was undertaken twenty-five years ago, but there is no production now.

Volcanic ash or pumicite suitable for mild abrasion, polishing and scouring is very abundant especially in the northeastern counties; Huerfano, Grand, Teller and others. The ash has been shipped from a number of eastern points, for the manufacture of mechanics' soaps, pastes, scouring and household polishing powders.

Massive garnet of good quality occurs at numerous places in the state but only west of the mountains is it found in quantity such as to make development appear possible.

Vein quartz is very abundant in the mining camps and a high grade milky quartz occurs in the great pegmatite dikes so common in the mountain zone of the state.

Basalt suitable for buhr stones is abundant, but the market is so limited and so distant that there is little chance of profitable development.

Corundum occurs in very limited quantity in several granite areas, but there is no promise of commercial quantities.

Pebbles suitable for pebble mills are quite abundant in southwestern Colorado, but except for a few attempts at local use there has been no production.

Road-making materials occur in great abundance. River gravels and sands are plentiful along the foothills. Residual gravels from the decay of granite in place occur in many parts of the pre-Cambrian area, and from the arkoses in other areas. Sedimentary and igneous rocks suitable for roadbed construction and for concrete aggregate are readily found. Asphaltic sands and sandstones are plentiful in the western counties and locally in the foothills.

INSULATING MATERIALS

Mica deposits are widely distributed in the pre-Cambrian rocks of Colorado. The available tonnage of mica is very large, and in many of the deposits there is a fair amount of excellent sheet mica, but, as in most occurrences of mica, the gross value will come from the small, or scrap mica, which is used as "splittings", "bran", and "ground" mica for fabricating into board, molded mica forms for heat, sound, and electrical insulation. Ground mica is extensively used in the rubber, patent roofing, paint, paper and other industries.

Muscovite or white mica is the most important member of the group, and is most extensively used in electrical engineering. It is used in sheet form for electrical insulation, for windows and stove doors, for peep holes in furnaces, and in other places where heat or shock would destroy glass.

Phlogopite is used for practically the same purposes as muscovite, but it is not yet found in commercial quality and quantity in Colorado.

Lepidolite is valuable chiefly as a source of lithium. It occurs at a number of localities in Colorado.

The vermiculites resemble the micas in structure, and are very hydrous alteration products from the micas, but differ from them according to the character and extent of the alteration. The plates are soft and inelastic and cannot be used for many of the purposes for which micas are used.

Jefferisite is a hydrated biotite which when heated exfoliates and takes on the color and metallic luster of gold and silver. It is used in decorative pigments and paper tinting. Jefferisite is found at various places in the state, and has been developed near Hecla in Chaffee County. Important veins occur near Westcliff in Custer County and near Iola in Gunnison County.

Mills for the preparation of mica for market have been built at several mica mines in the state, particularly in Chaffee, Fremont, Jefferson, and Larimer counties. Fremont has been the largest producer and the Micanite area in the northern part of the county was the center of a growing industry. Mines were also opened in the Royal Gorge and Texas Creek regions. The mica occurs with feldspar and quartz in pegmatite dikes cutting the pre-Cambrian schists, gneisses and granites.

The associated minerals are those characteristic of pegmatites and include feldspars, quartz, tourmaline, magnetite, beryl, cyanite, fibrolite, and others.

Several prospects and mines have been opened on the west side of the range but unfavorable transportation conditions have prevented development.

The Mesa County mica prospects are eight miles south of Grand Junction where pegmatite dikes cut pre-Cambrain schists and gneisses. Very little sheet mica can be got, but very high grade silvery muscovite scrap is abundant.

One of the most promising areas is the Buckhorn Creek southwest of Fort Collins in Larimer County. Some excellent sheet was produced and a high grade of scrap was prepared in the mill at the mines.

Diatomaceous earth is a very light, porous, finely granular, earthy material, composed mainly of the siliceous shells of diatoms (microscopic plants), but some deposits contain the siliceous shells of radiolarians in considerable quantity. It is called by various names, such as infusorial earth, diatomite, kieselguhr, desmid earth, radiolarian earth and others. The prepared earth appears on the market under various trade names, such as Sil-O-Cel and Filler-Cel.

The principal uses are for insulation, filtering, as an absorbent, an abrasive, a filler, and as a structural material in cut blocks and molded forms.

It is not yet known in commercial quality and quantity in Colorado, but a small deposit occurs near Denver and it has been reported from other parts of the state.

FILTERING MATERIALS

Fullers' earth is widely distributed in Colorado, but as yet the deposits lie undeveloped. High grade earth occurs near Akron and a small mill was erected for preparing the material for market. It is no longer operated. Excellent earth occurs near Sterling, near Delta, Hotchkiss, Grand Junction, near Telluride, in North Park and elsewhere. Several of these earths appear to equal the Florida product, but exhaustive tests have not been made. Fullers' earth is used in the decolorizing and deodorizing and filtering of oils, fats, greases and waxes, and as a scouring agent. The used earth is restored by washing with naphtha, and then calcining to a dull red heat.

It is also used as an absorbent in the cheap paint industry.

FLUXING MATERIALS

The principal use of fluorspar is as a flux in the basic open hearth process of steel manufacture, but it is also used as flux in the metallurgy of aluminum, gold, silver, copper, lead and zinc. It is especially effective in the treatment of siliceous ores. A small amount is used in the refining of lead, copper and antimony. Sodium fluoride is used as a preservative of wood.

Fluorspar is used in enamels, glazes and opalescent glass. A limited amount of fluorspar is used in the cement industry, and as a bonding agent in abrasive wheels and carbon electrodes. Hydrofluoric acid is made from fluorspar.

The mineral is widely distributed in Colorado, and a considerable tonnage is shipped to eastern markets. The only important local user is the Colorado Fuel and Iron Company which owns a large deposit at Wagon Wheel Gap. Fluorspar has been shipped from Wagon Wheel Gap, Jamestown, Evergreen, points near Colorado Springs, and from North Park. There are also large deposits in the San Juan, in the Barstow and other mines.

Dolomite is the carbonate of calcium and magnesium. Dolomitic limestone is used for lime. When the rock contains approximately equal proportions of the two carbonates it may be calcined and converted into a highly refractory material suitable for linings for iron and steel furnaces. The comparatively low price of calcined magnesite prevents the extensive use of calcined dolomite.

Dolomite occurs abundantly in several parts of the state, but the dolomites of the Leadville district are well known, and in the early days of Leadville smelting were used for flux in the smelters.

CHEMICAL MATERIALS

Strong veins of barite occur in the vicinity of Boulder and Jamestown, and near South Boulder Creek in Boulder County. Shipments of several carloads have been made from the veins in Sunshine Canyon west of Boulder.

Barite has also been produced in certain Aspen mines.

Barite has many uses in the arts and industries, but the greatest demand is in the paint industry where it is used with white lead and zinc white in white paints, and in a pigment known as lithopone. Barite is also used in the pottery, packing, beet sugar, paper, rubber, tanning, enameling and other industries. Obsidian or volcanic glass is used to some extent as an abrasive. The granulated obsidian is spread on paper and cloth to form sand paper and abrasive cloth.

Obsidian occurs in Clear Creek, San Juan and La Plata and other counties. On the slopes of Engineer Mountain a beautiful green obsidian occurs in dikes.

Monazite is a phosphate of the metals cerium, lanthanum and didymium, and generally contains thorium oxide. It is the principal source of thoria used in the incandescent gas-mantles, and is an important source of cerium. It occurs in the sands of practically all the streams flowing from the pre-Cambrian area of the state.

The reddish, reddish-brown, clove-brown and yellowish-brown grains are much heavier than the quartz sand and may be easily separated by placer washing.

Native sulphur occurs in several localities in Colorado, and attempts have been made to develop some of the deposits but up to the present the production has been small, and the properties are now idle.

Among the most promising deposits are those in Gunnison, Mineral and Delta counties. In all these the sulphur is associated with pyrite and is probably derived from the pyrite.

Pyrite (iron sulphide) occurs in great abundance in almost all the mining districts of the sulphide belt extending from Boulder County in the northeast to the San Juan in the southwest. From 1885 until 1920 pyrite, pyritic ores of gold and silver, and the sulphide ores of lead and zinc were extensively used by the Western Chemical Works Co., and its successor, the Western Chemical and Manufacturing Co., in the manufacture of sulphuric acid and other chemicals. Since 1920 the easily mined native sulphur of Texas and Louisiana has displaced the Colorado sulphides in the chemical industry of Colorado.

During the war pyritic ores were used in the Du Pont powder plant at Louviers.

Cryolite occurs in small amount at St. Peters Dome.

The Morrison formation contains sand suitable for the manufacture of glass, and at one time a small plant in Denver used sand from the Morrison in the southern part of Jefferson County.

Foundry sand of fair grade is dug for local use in several counties along the eastern slope of the range, but the best molding sands are imported from the east.

Alunite is a hydrous sulphate of aluminum and potassium, from which potash may be derived by a comparatively simple process.

Alunite occurs in promising quantities in the Rosita Hills, Custer County, and on Calico Peak in the Rico Mountains. Some development has been done in the Rico Mountains.

Potash has been found in one or more wells drilled for oil in western Colorado. The mineral is carnallite, the double chloride of potassium and magnesium. No attempt has been made to determine the extent of the deposit.

REFRACTORY MATERIALS

Pure graphite is elemental carbon, occuring in both crystalline and amorphous forms. Its fusion temperature is probably above 3000°C, but it burns slowly at very high temperature. It is not soluble in acids and is otherwise chemically very inert. It is soft and unctuous, and conducts electricity rather readily. These physical and chemical properties determine its uses, the most important of which are the manufacture of crucibles, the facing of covers, and molds in foundry work, the making of paints, lubricants and polishes, and so-called lead pencils. In several of its more important uses clay is used as a bonding agent.

It occurs under many geological conditions in all three of the great rock groups—igneous, sedimentary and metamorphic. At various points in Colorado it has been formed as a result of the intrusion of coal beds by igneous rocks. Other deposits have been formed by the dynamic metamorphism of coal. Small deposits occur in the granites and schists.

The principal production has come from near Turret in Chaffee County where Paleozoic sediments, granite, pre-Cambrian metamorphic, and recent Tertiary eruptive rocks are in close relationship.

An undeveloped deposit of graphite lies east of Anthracite in Gunnison County. Large deposits resulting from the alteration of coal occur on the slopes of Italian Peak in the Elk Mountains.

Carbonite, an impure graphitic material, occurs in the Trinidad, Anthracite and Crested Butte and California Park coal areas.

Ganister is a highly refractory siliceous sedimentary rock containing 98% of silica and not more than 1.5 per cent of alumina, and of such structural character that it may be crushed into fine angular fragments.

The even texture quartzites in the pre-Cambrian of many parts of the state answer all the requirements and some of them have been tested and found very satisfactory. They occur at many points along the eastern foothills, as at Coal Creek, South

Boulder Creek, Big Thompson River, Buckhorn Creek; near Salida, in the Needle Mountains and elsewhere.

Zircon is the silicate of zirconium. It is used in the manufacture of refractory materials of various kinds, particularly furnace linings. It occurs sparingly in the syenitic and more basic rocks of Colorado, and in the vicinity of St. Peter's Dome there is a zircon syenite which may prove to be a possible source of zircon.

Asbestos occurs in the pre-Cambrian metamorphic rocks in the neighborhood of Camp Albion in western Boulder County. The prospect of commercial production is not good.

Chapter 9

WATER RESOURCES, SOILS, FORESTS, PASTURE LANDS AND FORAGE PLANTS

WATER RESOURCES

The rainfall map of the state shows that the precipitation in all that area east of the foothills ranges from 13 to 20 inches per year. The low evaporation rate during the winter and early spring months and the rainfall of April give the farmer a soil well charged with deep moisture for the spring seeding, and this moisture persists well into and frequently through June. Very fortunately in the following four months, May, June, July and August, which may be called the growing months, the total rainfall averages 75 per cent of the total for the year. The result is that the agricultural possibilities of eastern Colorado are far greater than would seem possible in consideration of the rather low annual precipitation over the area.

The progressive farmer on the non-irrigated lands of eastern Colorado conserves the moisture by summer fallowing, and the cultivation of crops such as corn and beans, which require several plowings to keep down the weeds. The plowing is done at such times and in such a way as to aid the soil in storing up the moisture. The fallowed land and the corn land are brought into fine condition for the fall seeding, and crops of winter wheat rivalling those of the prairie states are becoming the rule in this area.

The central zones of the San Luis Valley, and North Park, the valleys of the Uncompahgre, Gunnison and Colorado Rivers from Montrose to the Utah line, and small areas near Gunnison and Buena Vista, and a few townships in the southwestern corner of the state have the lightest rainfall—not exceeding 10 inches per year. In the San Luis valley the abundance of artesian water and the streams flowing from the surrounding highlands have made irrigation so generally possible as to compensate very liberally for the light rainfall. North Park has much water available for irrigation, and large areas in the valleys of the Uncompahgre, Gunnison and Colorado are unsurpassed in agricultural productivity by reason of irrigation and the favorable distribution of the annual precipitation.

Other parts of western Colorado compare favorably with the eastern plains in the matter of rainfall, but the area having an annual rainfall between 10 and 13 inches in the west and northwest is greater than the corresponding area along the Arkansas from Canon City eastward. In part of this area of low rainfall in the northwest the greater elevation and the consequent lower mean temperature reduce evaporation and in a measure compensate.

On the other hand the greater average elevation of the western plains has given a larger area having a precipitation between 15 and 20 inches than there is on the eastern plains. The summer and late spring precipitation is a very beneficent feature of Colorado climate from the standpoint of agriculture and stockgrowing.

IRRIGATION

In the great mountain zone of the state where but little land is cultivated, the rainfall averages over 25 inches per year, and in many of the higher areas exceeds 40 inches per year. In this zone the mean temperature is low and the loss by evaporation is small; the soil or mantle rock is thin and comparatively little of the water enters and remains in the ground. The topography is steep and, as a consequence of all these conditions, the runoff to the plains east and west of the range is very great.

The pioneers of the log cabin, the sod hut, the dugout and the adobe shelter had scarcely provided themselves with shelter before they began to put to use these long unharnessed waters both for power and for irrigation. Here began the industrial development of Colorado and the conquest of the socalled "great American desert".

First by direct flow and later by storage in reservoirs these waters were made to supplement the rainfall on the plains, and one of the greatest achievements of the State is the beneficial use of her waters whereby over 3,600,000 acres of rich soil are watered and made to yield crops far greater than the rich prairie lands of Iowa. The 28,000 miles of canals and ditches by which these waters are distributed are sufficient to add another million acres to the garden lands of the state.

Long usage of these waters has gradually filled the ground and raised the water table until there is a return flow to the streams which is adding greatly to the possible service or duty of the waters. Not only are these waters returning and made available for reuse but the continued irrigation is so charging the deeper soil that a smaller quantity of water is now necessary to meet the real necessity of the crops than formerly, and by this means the area under irrigation may be increased.

Carefully compiled data show that the streams of Colorado are discharging to bordering states over 13,000,000 acre-feet of water—an amount far in excess of the decreed water priorities of these bordering states. This excess may be legally stored for use in the state.

It is the belief of many well informed engineers and water users that in many places the present consumption of water is harmfully large, and that by a more economic use of waters now available, the increasing return by seepage and the construction of reservoirs, the irrigated area in Colorado could be raised to 7,000,000 acres or more.

WATER FOR POWER

The value of a stream for power purposes depends mainly upon volume carried, constancy of flow and fall. Two streams may discharge the same annual volume, and have the same total fall, but the one may do practically all its work in a few months while the other may carry an even volume the year round. One may have a uniform gradient or fall from head to mouth, while the other may have most of its fall in a few miles and be sluggish the remainder of its course. Since the energy of a stream may be measured roughly by multiplying its volume by its fall, it is evident that so far as energy is concerned a stream may make up in greater fall what it lacks in volume.

As a rule power is required in nearly equal volume the year round. Without storage facilities to equalize the supply of water to the power plant, and without other sources of power for the low water season the value of a stream for power purposes is measured by its low water flow.

Other things being equal, a stream having very high gradient or fall in part of its course can be more advantageously used for power than can one of uniform gradient throughout its course.

As the rainfall is much greater, the topography much steeper and the runoff much greater in the mountain zone of the state than in the plains area, a very large part of the waters carried by the streams comes from this part of their drainage basin. But the precipitation in the higher regions is quite largely snow which accumulates during the cooler part of the year, and melts in the summer at the time when the precipitation is in the form of rain. It is evident that the streams will be very low in the winter and proportionately high in the summer. Unless the excess of summer flow can be stored for winter use the stream's value as a source of power is comparatively small.

Colorado has no large rivers, but she has many streams having such a great fall that, though of relatively small flow, they may be made to yield a great volume of power. Such streams as the Arkansas and the South Platte cross the state line at points over 6,000 feet lower than the sources from which they flow. The Colorado sends the waters of the Eagle, the Gunnison, the Uncompahgre, and her own into Utah at an elevation under 4,500 feet, from sources ranging up to 14,000 feet.

A study of the power possibilities of the streams of the state by the U. S. Geological Survey has given the following figures:

Horsepower available without storage for 90% of the time	765,000
Horsepower available without storage for 50% of the time	1,570,000
Horsepower available from storage of water	2,568,200

From this tremendous storehouse of energy only 72 water power plants are drawing, and their total installed capacity is 96,838 horsepower. If all pending permits are granted the total will not exceed 131,000 horsepower.

The Federal government controls the water power and permits for its use must be granted by Washington.

But though the actual horsepower developed seems to be small the state has made a good record since its first use of water for power purposes 65 years ago.

One can foresee the day when under State control this vast volume of energy passing uselessly year after year will be harnessed and made to plow our fields, harvest our crops and serve the people of this commonwealth in a hundred ways.

The first use of water for power in Colorado was in the mining camps where it hoisted the ores, turned the arrastres, drove the mills and pumped the water from the mine. Then followed the water power flour mill, and the power pump for raising water for irrigation.

To the city of Aspen belongs the honor of having the first hydro-electric plant in the state, and the further distinction of "being one of the first towns in the world to have its buildings and streets generally lighted"*. This installation was made in 1885, and was soon followed by Glenwood Springs, Buena Vista and many others. In 1890, wires from what is now known as the Revenue Tunnel plant No. 2, were run into the mine and for the first time electric power was used for drills and motors.

From this time on the development of hydro-electric plants both for power and for lighting was rapid.

The number of water power plants of Colorado, their capacity and use are shown in the table below:

	No.	H.P. Capacity
Individual mining plants	32	11,874
Public utility (chiefly mining)	9	25,890
Public utility (chiefly urban)	20	55,103
Irrigation pumping	4	3,350
Flour mills	7	648
Total	72	96,838

WATER FOR STOCK AND DOMESTIC USE

Artesian waters are found in many localities in Colorado but in only two have they been developed to an important extent. The San Luis valley and the Denver Basin are the conspicuous examples of such development. Flowing wells have been obtained at Pueblo, Florence, Canon City, Rocky Ford, La Junta, Holbrook, Las Animas, Lamar and many other places in southeastern Colorado. In western Colorado artesian flows are not so common, though there are many places where a study of conditions might lead to the development of small artesian basins, and the extension of areas already known, such as those of the Uncompahgre Valley.

In the Denver Basin artesian waters may be drawn from the Denver, the Arapahoe, the Laramie and the Fox Hills formations, but the most important of them is the Arapahoe. All but the Fox Hills yield a pure soft water.

*Follansbee, R., the Engineers' Bulletin, Sept. 1926, p. 5.

The development of artesian water supply began in 1883, though some unsuccessful borings had been made about ten years earlier. Many of the earlier wells flowed freely, but as the number of wells and the consumption of water increased the head was lowered and flowing wells were rarely secured. The wells range from 400 to 1,200 feet in depth, depending upon the part of the basin they are in and the water sand from which they draw. Artesian wells are still extensively used in the city, and numerous wells have been drilled in the last few years, but very few wells now flow.

The basin is about 25 miles long, from Littleton to Henderson, and about 10 miles wide following the course of the Platte River.

The San Luis artesian basin is by far the largest in the state and one of the largest in the country. The area of flowing wells is 65 miles long and reaches a maximum width of 30 miles. Outside this is a wide border in which an abundance of water rises to within a few feet of the surface and is easily available by pumping.

The flow of the 4,000 wells is sufficient to irrigate 25,000 acres of land. On the assumption that the irrigation season is four months, the total annual flow of the wells would be enough to irrigate 75,000 acres.

This basin is amply supplied by the streams flowing from the surrounding mountains.

In the matter of water the San Luis valley is one of the most favored areas of the country, since it has not only the artesian waters but also those of the rivers carried by ditches to the land.

Considering the limited rainfall of the state Colorado is remarkably well supplied with water for stock and domestic purposes. Of the eastern part of the state north of the Arkansas River a very large part is occupied by formations carrying sandstones in most of which pure, soft waters may be found. Such sandstones occur in the Dakota, locally in the Benton and Niobrara, abundantly in the Fox Hills, Laramie, the Arapahoe and Denver, and in the great Tertiary area of the eastern border. Only in the areas occupied by the Pierre, the Carlile part of the Benton and the more shaly part of the Niobrara is the question of water very serious. Much of the water from the deep shales of these formations is alkaline, but a large part of it can be rendered usable by water softening compounds.

In eastern Colorado south of the Arkansas River the Dakota and the Tertiary formations furnish good waters and are in most places reachable. In western Colorado the conditions are similar to those of the eastern plains. The same formations are present and the possibilities are parallel.

The mountain zone is one of heavier rainfall, many springs, and rushing mountain streams.

SOILS OF COLORADO

The soil of Colorado is her most important resource. Its annual return far exceeds that of the mines, and with proper use there is no liklihood of its exhaustion within many generations.

Colorado has many different kinds of rocks and as rocks are the original source of the inorganic part of soils, one might expect remarkable diversity in the composition of soils. The most important constituents of soils are, first, *rock powder* derived by mechanical means from the rock formations; second, *clay* derived by chemical changes due to weathering; and, third, *humus*, the residue from plant decay. From the standpoint of physical and chemical conditions soils are classed as gravelly, sandy, silty, loamy, calcareous, siliceous, and magnesian.

According to the means by which they reached their present position soils are *residual* or *sedentary*, *colluvial* and *alluvial*. Residual soil is one formed by weathering of the underlying rock, and remains in the place of its formation. Such soils are common in the flat areas of poor drainage, such as the eastern plains, especially far from streams.

Colluvial soil is one formed by the bringing together of the products of decay of different areas and different rock types, by the action of rain wash, slipping, wind action and gravity. They are the common soils of all the mountain areas except the glacial lake basins, and mountain meadows.

Alluvial soils are formed by the deposition of sand, clay and rock powder carried by streams. They are the soils of stream valleys, flood-plains, lake borders and the basins of extinct lakes.

These soils may be of decidedly mixed composition, or they may be homogeneous as a result of assortment by the water.

The soils of Colorado have formed under a wide variety of climatic conditions. Those of the eastern and western plains have been formed under a mean rainfall of 10 to 20 inches per year and temperatures ranging from 90°F. to a few degrees below zero F. Those of the mountains have been formed under much greater rainfall and a much wider range of temperature, where both mechanical and chemical disintegration have been more rapid, and where the contribution of plant life has been much greater. The plains soils are much lower in humus than are those of the mountains. They are more largely composed of unaltered rock matter, and as a consequence are higher in phosphorous and potash, iron and magnesium. The leaching process has fortunately removed much of the more readily soluble sodium salts. But as potash has a strong affinity for clay it has been retained for plant use.

The lime content of the plains soils is much higher than might be expected when the rocks of its origin are considered. This is due to water action which has collected the lime and brought it up toward the surface and deposited it in the soil layer.

In many parts of the eastern and western plains a soil has been formed through the selective action and transportation work of wind. Such soils are well suited to wheat growing but must be handled carefully.

Most of the soils of Colorado, by reason of the conditions of their formation are rich in the essentials for plant life such as potash and phosphorous, lime, iron, magnesia, sulphur and silica. In many places they also retain soluble salts of the alkali varieties, as well as the rock matter from which by weathering processes such salts are formed. But as these salts are mainly of the sulphate type they are rarely irremediably harmful. In regions of greater rainfall these salts are washed out and carried away. In irrigated areas of poor drainage care must be used to avoid undue increase of these salts in the soil. Proper use of water may be made to rid the soil of any excess.

Colorado soils present sufficient variety of texture and composition that by careful selection soils suitable for any crop, or fruit for which the climate is suited, may be found. The crops of the irrigated areas are not excelled in any part of the country.

The soils of the plains are, for the greater part of such physical and chemical makeup as to fit them for the storing of moisture, and the farmer of the non-irrigated lands is fast learning to store and conserve water in the soil to such an extent as to produce crops which rival those of the regions of greater rainfall.

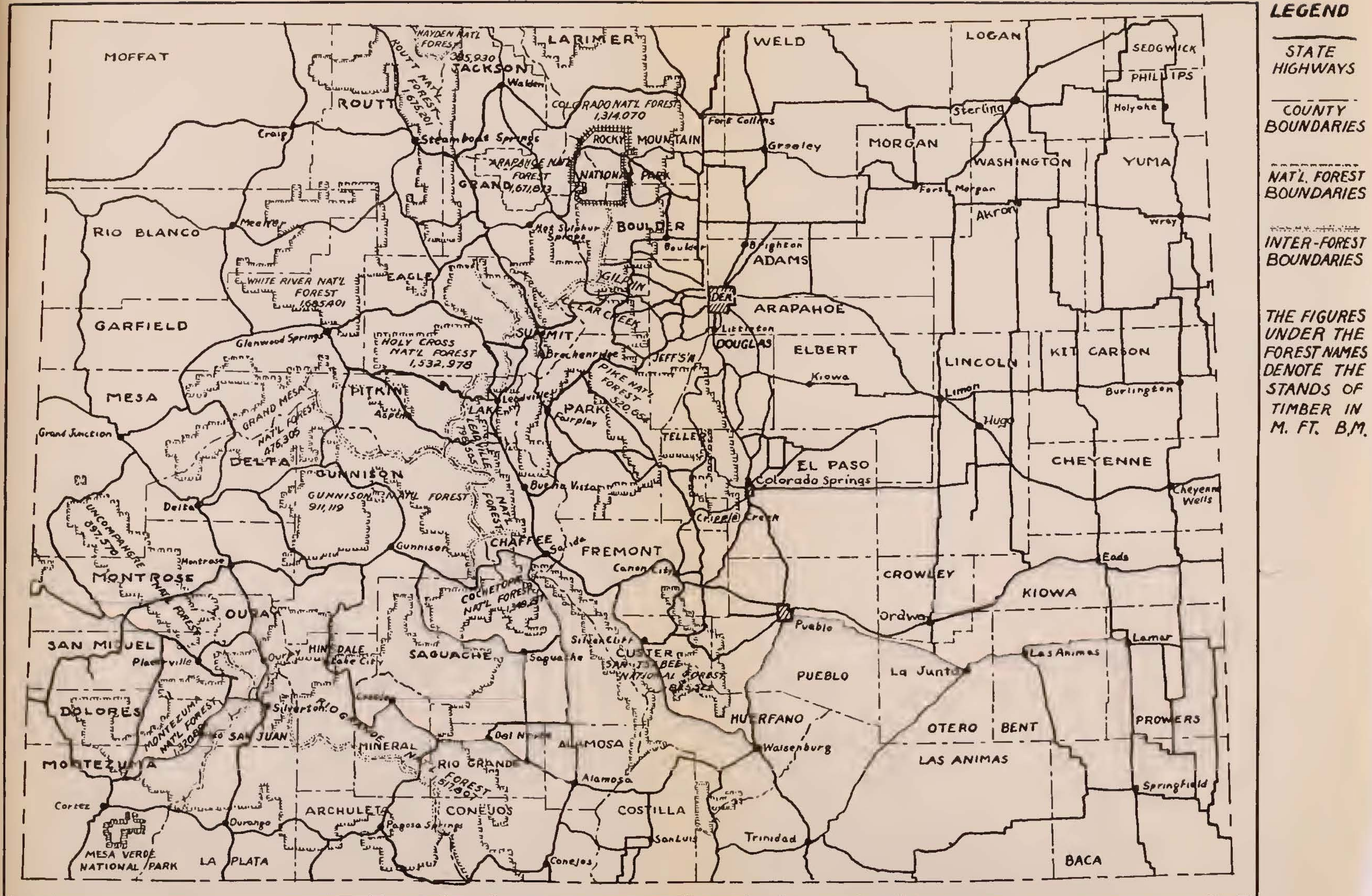
The distribution of rainfall in Colorado is very favorable for the cultivation of the soil.

THE FOREST RESOURCES

The National Forests have an area of 13,250,000 acres. These lands are adjudged to be more valuable for the preservation and production of timber than for any other purpose. Outside these forests are hundreds of thousands of acres of forested land under private ownership, and other large areas of federal lands too sparsely timbered to justify including them in the National Forests. The state also owns forested lands.

The forested areas of the state are mainly in the mountains and high plateau areas where the rainfall exceeds the average for the state, and where evaporation is slower and the conditions for timber growth are the best. Three groups of conifers—spruces, pines and firs—furnish practically all the timber of the state. The Engelmann spruce outranks all other timber trees and gives the state over one-half its stand of timber—thirteen billion board feet. Next in order is the lodgepole pine which is credited with providing four and one-quarter billion feet, board measure, of standing timber. The western yellow pine, two billion; the Alpine fir, one and one-half billion; the Douglas fir, one billion, stand next. Below these and furnishing, in all, about two hundred million board feet of timber, come in order the white fir, the limber pine, the blue spruce, the pinyon pine, the juniper and bristlecone pine.

The most important of the National Forests is the San Juan, containing somewhat over one-quarter of the timber—largely Engelmann spruce. Then follow in order the White River, the Routt, the Arapaho, the Holy Cross, the Rio Grande, each having in the neighborhood of one and one-half billion board feet. The Cochetopa, the Colorado and the Montezuma fall a little below



HIGHWAYS AND NATIONAL FORESTS

one and one-half billion feet each, and the remaining forests, each with less than one billion board feet, stand in the order: Gunnison, San Isabel, Leadville, Pike, Grand Mesa, Uncompahgre and Hayden.

Timber ready to cut either because of maturity, disease or the need of thinning to promote a better forest growth, is selected, marked and offered for sale "on the stump". The cutting is supervised to prevent injury to the standing timber, by fire, breaking or otherwise. In this way the health and productivity of the forests are promoted. The utmost vigilance is exercised to detect disease, and destructive insect pests, and to check and prevent their spread.

The cutting in the Colorado forests is between 50 and 60 million board feet per year, while the rate of growth is estimated at 300 million board feet per year. This is a net increase of approximately 250 million board feet per year. This would double the present stand in about 60 years.

Reforestation is receiving increasing attention and already over 10,000 acres have been planted with from 250 to 500 trees per acre. The annual planting is from 1,000 to 1,200 acres, at a cost of $10.00 to $15.00 per acre. This praiseworthy work has been done mainly in the Pike National Forest. The area suitable and ready for reforestation within the National Forests of the state is 900,000 acres. The planting has been mainly western yellow pine, Douglas fir and Engelmann spruce.

The forested area of Colorado outside the National Forests is 1,340,000 acres. This includes forested state lands and privately owned forests. Much of this land is adjacent to the National Forests and is timbered by the same species. The principal varieties are the western yellow pine, the Douglas fir, the Engelmann spruce and the lodgepole pine. Subordinate types are the Alpine fir, white fir, pinyon pine, bristlecone pine, limber pine, Rocky Mountain red cedar, aspen and cottonwood.

The estimated stand of merchantable timber is 3,750,000M board feet. The annual cut is estimated at 7,000,000 feet board measure, and the annual growth is probably double that figure. Tree-planting by the farmers of eastern Colorado amounts to about 300 acres per year.

Reforestation in the National Forests of Colorado will cover

1,200 acres this year (1927) according to plans announced by Col. Allen S. Peck, District Forester, Denver. All of this except about 100 acres will be planted on the slopes of Mt. Herman in the Pike National Forest directly west of Monument. The remainder of the planting will be on Marshall Pass in the Cochetopa National Forest, about 35 acres; on the watershed of Fruita in the Grand Mesa National Forest, about 30 acres; on Cumbres Pass in the Rio Grande National Forest, about 8 acres; small experimental plots throughout the other National Forests of the State, about 25 acres. This will require a total of 775,000 trees, all of which will be supplied by the Forest Service nursery at Monument.

In addition, about 125,000 trees from the Monument Nursery will be distributed through State officers of Colorado, Wyoming and Kansas, at cost to ranchmen, under the provisions of the Clarke-McNary law.

Work on government land will probably begin at lower elevations the latter part of April and continue several weeks. Where planting is done at high altitudes activity will go on until June. Yellow pine will be used chiefly in the former locations and Engelmann spruce in the latter, while Douglas fir will be planted at middle elevations, according to the natural distribution of these species.

While planning future activity it is necessary to observe carefully and interpret the results of the past, according to the District Forester.

Weather conditions during the first few years, the site on which the planting is done and the condition of the nursery stock are the important factors in the success of reforestation. In the case of Douglas fir, three-year old seedlings have been found to be the hardiest also the cheapest planting stock for this species.

Work is being done at the nursery at Monument to provide for a greater output to take care of both limited expansion of activities on the National Forests and the increased demand from ranch owners through State Foresters in nearby states. Enlarged water storage facilities have been developed, also the use of a fungicide which prevents what in the past has seemed an unavoidable loss from root rot.

The altitude ranges of the important forest trees of Colorado are approximately as follows:

In northeastern Colorado.

Yellow pine and Douglas fir zone,	6,000— 8,000 feet
Lodgepole pine,	8,000—10,000 feet
Engelmann spruce and balsam fir, or timberline.	10,000—11,500 feet

Southern Colorado.

Pinyon pine and juniper,	5,500 or 6,000— 7,000 feet
Oak chaparral often associated.	
Yellow pine and Douglas fir,	7,000— 8,500 feet
White fir zone,	8,500—10,000 feet
Engelmann spruce and balsam fir,	10,000—11,500 feet

San Luis Valley.

Pinyon pine and juniper,	8,000— 8,500 feet
Yellow pine and Douglas fir,	8,500—9,000-9,500 feet
Lodgepole pine,	9,500—10,000—10,500 feet
Lodgepole pine is rare on the east side of the valley. White fir may here take its place.	
Engelmann spruce—balsam fir, to timberline.	10,000—10,500 feet

Northwestern Colorado.

Chaparral, chiefly oak and buckbrush,	6,000—7,000— 8,000 feet
Lodgepole pine, Aspen abundant.	8,000—10,000 feet
Engelmann spruce and balsam fir,	10,000—11,500 feet

Southwestern and middle western Colorado.

Pinyon pine and juniper,	Variable vertical range
Yellow pine and Douglas fir, (Douglas fir frequently goes beyond yellow pine. Aspen well developed)	7,000 or 7,500—8,000 or 8,500 feet
Engelmann spruce and balsam fir, up to timberline.	

Middle and North Parks.

Above sage brush come lodgepole pine and aspen.

The zones are rarely clearly defined and mingling extends over a considerable area.

Yellow pine is always a tree of lower altitudes than lodgepole, and lodgepole flourishes at lower elevations than Engelmann spruce and balsam fir.

Douglas fir associates with yellow pine and lodgepole pine but does not go far into the lodgepole belt.

Aspen grows in open spaces at all altitudes from 5,000 feet to timberline, but is best developed in the lodgepole zone. White fir has about the same altitude range as lodgepole pine.

Scrub oak is absent from the northeastern part of the State, North Park, Middle Park and South Park.

It extends north to between Palmer Lake and Denver, and sometimes forms a fringe just above the sage brush.

It also associates with pinyon and juniper. It does not succeed well above 8,000 feet. It seeks a deep, rich agricultural soil.

RECREATION IN THE NATIONAL FORESTS OF COLORADO

Recreation is considered by the Forest Service of the Department of Agriculture as one of the four basic resources of the National Forests of Colorado. Simultaneously with the development of timber, forage, and watershed protection, recreation resources are being made available to the people to whom they belong. The social value of the National Forests in Colorado to the people of the Nation in the form of public playgrounds may be judged when it is known that in 1926 1,844,159 people visited the Forests in the state. What the economic value to the state is, can be judged by multiplying the number of visitors to the Forests by the average expenditure. Placing this at the very conservative figure of $20.00, the economic value of recreation would total around $37,000,000.00.

The Federal Government thru the Forest Service has spent many millions of dollars in opening up roads and trails within the National Forests of Colorado. While the controlling feature of all road and trail plans has been protection from fire and the opening up of the economic resources of the Forests yet in each case the development of recreation resources is also considered.

Recreation is being developed in a wise fashion. All National Forest areas are first classified as to probable intensity and the type of recreational uses that should be developed. On the foundation of this classification each region is then carefully examined and plans for its development made. These plans include the layout of roads, trails, location of resorts, summer homes and public camp grounds. The relation of human use to municipal water supplies and their protection is an important item. Game and fish must be considered and the whole tied in and considered with plans for the use of timber and forage. Fire protection systems must be intensified as recreational use grows. Planning of recreation is a highly skilled job and the best knowledge and experience of the Forest Service is being applied to this work in the National Forests of Colorado and every effort is being made to conserve recreation resources for the public to put them to their highest use.

It is a fundamental policy of the Forest Service to place a minimum of restriction and supervision on public use of the National Forests. The charm of a vacation in the Forests is materially enhanced in the view of the Forest Service because of this freedom of action and use. Education of the public to use care with fire and exercise the ordinary courtesies of the woods by leaving clean camps is being carried on and the results are good.

As time goes on these public properties will become more and more intensively used and of greater value. Since the use is so largely by people outside the State it is but proper that they should be developed by the nation.

PASTURE LANDS AND FORAGE PLANTS OF COLORADO

The pasture lands of the state fall into two main groups: Those privately owned and those publicly owned. In 1925 there was a total of 19,543,000 acres of privately owned pasture land, of which 5,114,000 acres were plowable. Much of this is dry land.

The pasture lands publicly owned are as follows:

National Forests	13,249,000
Public Domain, federal	7,464,000
State Lands	2,883,000
	23,596,000

In addition there are about 3,480,000 acres of federal land filed upon but not patented.

Of the National Forest lands about 10,000,000 acres are used for grazing under paid permits, and support about 290,000 cattle, 6,000 horses and 895,000 sheep.

There is no control of grazing on the federal public domain, consequently much if it has a very low grazing capacity due to overgrazing. Most of the state land is leased for grazing purposes.

Grazing is one of Colorado's most important industries, at least two-thirds of its land area being primarily for this purpose. Many grazing types are found within the state. The grazing capacity and range management depend upon the character of the plants growing in these types.

Most of the eastern third of the state is in the Great Plains and is characterized by vegetation composed largely of short-grasses. The chief ones are grama grass and buffalo grass. These cover the ground in the form of mats with leaves usually only three to four inches tall. These grasses are highly drought-resistant and are very nutritious and highly palatable to stock even when dry. The grazing capacity ranges from 15 to 50 head of cattle per section during the growing season. The presence of western wheat grass among the short-grasses indicates the presence of deeper, moister soil; three-awned or wire grass indicates more sandy soil or overgrazing; snakeweed and cacti indicate overgrazing.

On more sandy soil, as in the vicinity of Wray, bluestem bunch grass is the dominant plant, often mixed with grama grass. It forms bunches a foot or so in diameter and one to two feet tall. The grazing capacity on these areas is high but the land must be carefully managed to prevent blow-outs due to overgrazing.

A grazing type known as sand grass and sand sage is found on the sandhills throughout the eastern quarter of the state. It is characterized by grasses, two to six feet tall, often with an understory of short grasses. The tall grasses are sand grass, sand drop-seed, bluestem bunch grass and tall bluestem, Indian grass and panic grass.

The short grasses are species of grama grass. The sand is usually sparsely covered by one or more of these dominant grasses as well as by other plants. It must be even more carefully managed than the bluestem bunch grass type because blow-outs start very easily. Sand hill sage, a bushy plant growing a foot to several feet tall, is often mixed with the grasses giving a grayish tone to the landscape. It increases under overgrazing by cattle.

On the plains bordering the eastern foothills and on the lower foothills the mixed prairie type of vegetation occurs. Tall grasses, such as the porcupine or needle grasses, western wheat grass, three-awned grass and, sometimes the bluestems and panic grass, are mixed with the short grasses, grama grasses, buffalo grass and sedges. A large variety of mountain plants such as beardtongue, sulphur flower, yarrow and others are mixed with the grasses.

The grazing capacity ranges from 20 to 60 head per section during the growing season. This type is composed of many highly palatable and very nutritious plants. Overgrazing by cattle causes the decrease and death of the tall grasses and increase in the short grasses and unpalatable plants, as gumweed, snakeweed and mountain sage.

The grassland extends up to 6,000-7,000 feet on the eastern slope of the mountains. A narrow interrupted belt of brushland is found between the grassland and the coniferous forest above. The brushland consists of mountain mahogany, chokecherry, thornapple, ninebark and other plants, all of which furnish browse for grazing.

In the western part of the state sagebrush is the dominant shrub growing usually at elevations up to 6,000 or 7,000 feet. Large areas covered with sagebrush and other similar shrubs, as rabbitbrush, extend as far east as the Laramie River Valley, in northern Colorado. Nearly one-fourth of the state is covered with this type of vegetation. There is usually considerable space between the sagebrush clumps. These are occupied by a variety of forage plants, such as the fescue grasses, wheat grasses, arid blue grasses and others. Much sagebrush range is grazed by sheep. The grazing capacity is about 15 to 25 head of cattle per section.

In the south central and western parts of the state a zone of woodland consisting chiefly of pinyons and junipers occurs at elevations usually below 7,000 feet. In many places it is mixed or alternates with sagebrush, in others oak brush is mixed with it.

Grama grass occupies much of the open spaces between the trees. The grazing capacity is low—10 to 25 cattle per section.

The yellow pine-Douglas fir forest forms a zone between 6,000 and 8,000 feet in the northeastern part of mountainous section and usually between 7,000 and 8,500 feet in the southern part. The lodgepole forest occurs between 8,000 and 10,000 feet, forming well defined zones in the northeastern and northwestern part of the mountainous section. The Engelmann spruce-balsam fir zone is usually between 10,000 and 11,500 feet, above which comes the alpine zone.

These timber zones contain a very large number of very palatable and nutritious grasses, as the blue grasses, fescues, brome grasses, June grasses, trisetums, alpine timothy, muhlenbergias, reed grasses, red tops, wheat grasses, as well as many species of weeds and browse. These range types are usually in the National Forests and hence the grazing is under the control of the Forest Service. The grazing capacity is high, averaging about 30 head of cattle per section. The alpine zone has a very short growing season but produces a large variety of valuable forage species, especially blue grasses and sedges. This range is utilized chiefly by sheep.

According to the United States Department of Agriculture Extension Service, the pasture lands of the state furnish annually 554 million animal unit days' feed, or enough to feed 1,244,000 cattle for a year. This is over two-thirds of the feed consumed by live stock of the state, including cattle, horses, sheep and swine.

Chapter 10

MINERAL WATERS, NATIONAL PARKS, FISH AND GAME

MINERAL WATERS

In the number of her mineral springs and in the variety of waters they pour out Colorado stands unrivalled among the states. It has been said that every well-known mineral water of European resorts has a duplicate in Colorado, and that every curative agency known in mineral waters is to be found in those of Colorado. Whether these claims can be verified or not, there can be no doubt as to the great variety of waters, their wide range of temperature, the abundant flows, the accessibility, the unsurpassed scenic beauty of their surroundings, and the invigorating climate.

The Bulletin on the Mineral Waters of the state, published by the Colorado Geological Survey, lists and describes 254 waters and the authors recognize the fact that their work was not exhaustive.

Many groups of springs have been developed and made the centers of health and pleasure resorts. Comfortable, and in some instances luxurious hotels have been built, swimming and bathing pools, bath houses, bath caves and tunnels, fountains, inhalation chambers and other facilities for using the waters have been provided. The surroundings have been beautified, trails built and many diversions provided.

From earliest recorded history, the origin of the waters of springs has been a subject of speculation and debate. Anaximines taught that water was condensed air, while Anaximander believed that air was rarefied water. Aristotle held that air imprisoned within the earth was condensed to water which found its way to the surface as springs. Descartes explained the existence of springs by saying that sea water entered subterranean caverns, became vaporized and after condensation rose to the surface of the earth by way of crevices.

A part of the water falling as rain upon the land enters upon a journey of greater or less length beneath the surface of the earth, and returns to the surface as the waters of ordinary springs, hot springs, mineral springs and geysers.

Again, water is present in almost all molten rock masses. As the rock crystallizes this magmatic water is forced out and may find its way to the surface alone or accompanied by waters of strictly atmospheric origin.

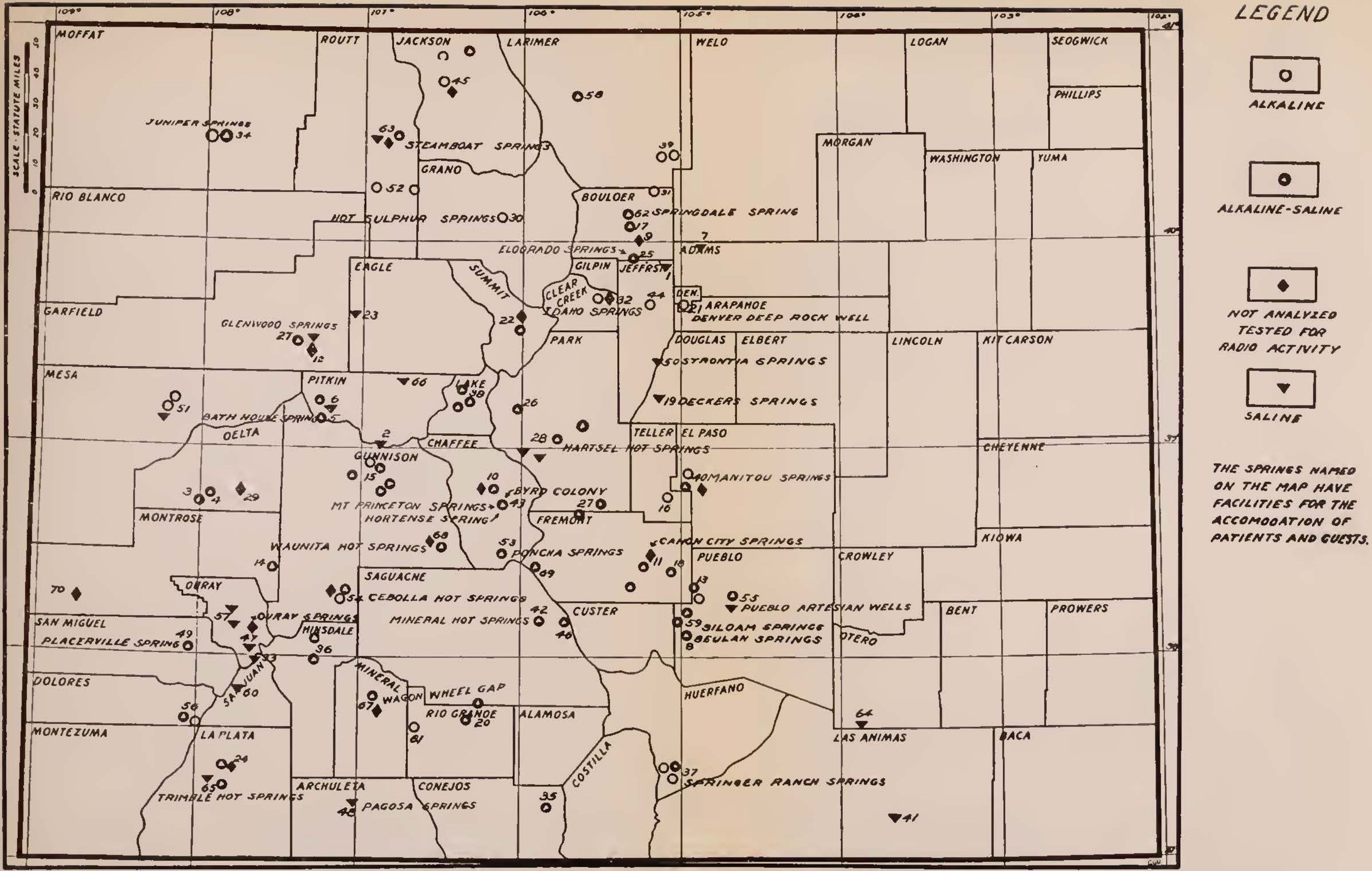
All these waters may be charged with mineral matter in solution gathered from the rocks in which they have been stored and through which they have passed in their journey. Some of the mineral matter may be gathered by simple solution and some by solution accompanied by chemical reactions.

The kind and amount of the saline matter gathered by waters will depend upon many factors, among which will be: the chemical and physical character of the rocks with which it has come into contact, the length of the journey, the time occupied, the temperature of the rocks and the temperature of the water. Some rocks contain much matter that is readily soluble, while others contain but little. Some are open and porous, or closely fractured, and as a consequence expose much surface to the water, and so favor the process of solution. Others are dense and comparatively free from fractures, and so offer but little opportunity for the waters to gather mineral matter by solution.

Carbon dioxide accompanies practically all volcanic activity, and is especially abundant in regions of dying, dormant, or recently past volcanic activity. Such regions are commomly noted for the abundance of mineral springs charged with carbon dioxide. In some places, as in the vicinity of Rico and elswhere in Colorado, vast volumes of carbon dioxide reach the surface as gas springs or "blows". The chemical activity of the carbon dioxide results in the formation of the various carbonates and bicarbonates found in mineral waters.

Sulphur gases are common accompaniments of volcanic activity, and in many places issue from vents in such regions long after all active vulcanism has ceased.

These gases include sulphuretted hydrogen and sulphur dioxide. Sulphur gases may also result from the breaking up of metallic sulphides such as pyrite, marcasite and others. Sulphuretted hydrogen may result from the breaking down of sulphates by organic matter, or other reducing agents.



MINERAL WATERS OF COLORADO

1. Arvada Spring (Golden Lithia Water).
2. Conundrum Springs, Pitkin Co.
3-4. Austin and Vicinity, Delta Co.
5-6. Avalanche and Vicinity, Pitkin Co.
7. Barrand Vicinity, Adams Co.
8. Beulah Springs, Pueblo Co.
9. Boulder and Vicinity, Boulder Co.
10. Buena Vista, Chaffee Co.
11. Canon City, Fremont Co.
12. Cardiff, Garfield Co.
13. Carlile and Vicinity, Pueblo Co.
14. Cimarron and Vicinity, Montrose Co.
15. Crested Butte, Gunnison Co.
16. Cripple Creek and Vicinity, Teller Co.
17. Crisman, Boulder Co.
18. Florence, Fremont Co.
19. Deckers Springs, Douglas Co.
20. Del Norte, Rio Grande Co.
21. Denver, Denver Co.
22. Dillon, Summit Co.
23. Dotsero, Eagle Co.
24. Durango, La Plata Co.
25. Eldorado Springs, Boulder Co.
26. Fairplay, Park Co.
27. Glenwood Springs, Garfield Co.
28. Hartsel and Vicinity, Park Co.
29. Doughty Springs, Delta Co.
30. Hot Sulphur Springs, Grand Co.
31. Hygiene, Boulder Co.
32. Idaho Springs, Clear Creek Co.
33. Ironton and Vicinity, Ouray Co.
34. Juniper Mineral Springs, Moffat Co.
35. La Jara, Conejos Co.
36. Lake City, Hinsdale Co.
37. La Veta, Huerfano Co.
38. Leadville, Lake Co.
39. Loveland, Larimer Co.
40. Manitou Springs, El Paso Co.
41. Mesa de Maya, Las Animas Co.
42. Mineral Hot Springs, Saguache Co.
43. Mt. Princeton Springs, Chaffee Co.
44. Morrison, Jefferson Co.
45. North Park, Jackson Co.
46. Orient, Saguache Co.
47. Ouray and Vicinity, Ouray Co.
48. Pagosa Springs, Archuleta Co.
49. Placerville, San Miguel Co.
50. Strontia Springs, Jefferson Co.
51. Plateau Creek Springs, Mesa Co.
52. Phippsburg, Routt Co.
53. Poncha Springs, Chaffee Co.
54. Cebolla Hot Springs, Gunnison Co.
55. Pueblo, Pueblo Co.
56. Rico and Vicinity, Dolores Co.
57. Ridgway Hot Springs, Ouray Co.
58. Rustic Lodge Springs, Larimer Co.
59. Siloam Springs, Pueblo Co.
60. Silverton, San Juan Co.
61. South Fork, Rio Grande Co.
62. Springdale, Boulder Co.
63. Steamboat Springs, Routt Co.
64. Symons, Otero Co.
65. Trimble and Vicinity, La Plata Co.
66. Thomasville, Pitkin Co.
67. Wagon Wheel Gap, Mineral Co.
68. Waunita Hot Springs, Gunnison Co.
69. Wellsville, Fremont Co.
70. Long Park, Montrose Co.

Chlorine and hydrochloric acid also accompany volcanic activity, and may be responsible for a part of the chorides of mineral waters. But the greater part of the chlorides probably comes from waters and salts held in sedimentary rocks, from the period of their formation.

The source of the heat of mineral waters is still a matter of discussion. There can be little doubt that in many localities it is due largely to recent volcanic activity. The Yellowstone Park is an area of this kind. In others the mechanical or frictional heat of the rocks, resulting from folding, faulting, uplift and other earth movements is responsible for the heat of the waters.

The waters of springs may range in mineral content from the merest trace to almost saturation, depending upon the length of their journey and the conditions encountered below the surface of the earth. The question naturally arises, When does a water become a mineral water?

The International Food Congress, which met in Paris in 1909, adopted the following definition:

"A mineral water is a natural water proposed for consumption on account of its therapeutic or hygienic properties."

This definition has been accepted by the United States Bureau of Chemistry and by the United States Geological Survey in its annual volumes on Mineral Resources. The chemist, the mineralogist and the geologist would regard such a definition as entirely too restricted, and would be disposed to accept the broad and very general definition given by F. W. Clarke. "A mineral water is merely a water which differs, either in composition or in concentration from the common potable varieties."

Writing from the standpoint of the physician, Dr. James K. Crook says:

"The term Mineral Waters is applied to those waters which are used in the treatment of disease, either by internal administration or by external application, and which owe their virtue to their solid or gaseous constituents, or to their elevated temperature."

In his report on "The Natural Mineral Waters of the United States," A. C. Peale defines mineral water from the physician's standpoint as:

"Any water that has an effect upon the human system, no matter how feebly mineralized it may be: that is, it is any water that possesses medicinal virtues, whether they be due to the presence of organic, inorganic, or gaseous contents, or to the principle of heat."

Since mineral waters are of value chiefly because of their healing properties, the physician's definition is the one commonly used in the discussion of mineral springs.

Thermal springs are those whose waters have a temperature above the mean annual temperature of the region in which they are located. Their waters may or may not carry more mineral matter than the common potable waters of the region. In common usage, however, only those springs whose waters have a temperature above 70° F. are termed thermal springs. Those having a temperature between 70° F. and 98° F. are classed as warm springs; those above 98° F. are called hot springs.

That the interior of the earth is very hot is proved by the issuance of lavas from volcanoes, by the higher temperatures at the bottom of deep mines and deep borings, by the heat of waters of geysers and hot springs, and by other observed facts.

In certain areas molten rocks have risen from deep within the earth to points at or near the surface. The heat from these masses raises the temperature of the rocks on all sides, and groundwaters circulating in such regions and coming into contact with these superheated rocks are highly heated and return to the surface in hot springs and geysers.

Earth movements are another recognized cause of heat. In the tremendous upheavals which have produced mountain systems and ranges, the folding, fracturing and crushing of rocks must have produced an extremely large total amount of frictional or mechanical heat.

It is a significant fact that thermal springs are most abundant in mountain regions, and especially in those parts where faulting and zones of weakness have favored the movement of rock masses over one another. Thus the zones of contact between the ancient granites and gneisses on the one hand, and the sedimentary formations on the other, are, as a rule, rich in thermal springs.

It seems probable, therefore, that great earth movements have caused the heat which gives many mountain springs their high temperatures. It must be borne in mind, however, that mountain regions are notably regions of volcanic activity, and that in many places highly heated igneous rocks may lie at no great distance below the surface.

The discovery of radium has led to much speculation as to the possible relation of the interior heat of the earth and volcanic phenomena to radioactivity. But there is, as yet, no theory which has found general acceptance. There seems to be no general relationship between the temperature of mineral waters and their radioactivity. In some places thermal spring waters are more radioactive than are cold spring waters. In Colorado the most highly radioactive waters are cold.

It is certain, however, that thermal springs, and mineral springs in general, are more common in mountainous areas than in low, flat plains; and highly mineralized waters are more common in areas where volcanic activity is, or has been, pronounced, than in areas remote from such past or present activity.

The use of waters for medical and bathing purposes antedates written history and appears to have been practiced by all branches of the human race. Many ancient peoples, among whom were the Egyptians and Hebrews, regarded bathing as a sacred rite, and the Christian rite of baptism as a symbol of spiritual healing or cleansing perpetuates the less significant Jewish rite of bathing. In some lands certain rivers were believed to be favored by the gods, and bathing in them was supposed to be attended by miraculous healing. The Nile in Egypt, the Ganges in India, the Jordan in Palestine and the Tiber in Italy were sacred rivers, and the bather in them was healed or otherwise blessed.

The history of mineral waters also dates from very remote times, and the most ancient historians and poets wrote of them. The medical writers of all ages refer to their curative properties and give instructions for their use in the treatment of diseases. Pliny says of mineral waters: "They spring wholesome from the earth on every side, the cold, the hot, the hot and cold together . . . or yet the warm and tepid, announcing relief to the sick, and flowing from the earth only for man, of all living things."

All nations have used them and among the more advanced peoples of ancient times temples, hospitals, medical schools, baths and resorts were erected in the neighborhood of mineral springs. "For five centuries mineral waters were almost the only medicines used in Rome." In European countries the value of mineral waters seems to be more generally understood and appreciated than in America.

CLASSIFICATION OF MINERAL WATERS

The following classification of mineral waters worked out by J. H. Haywood and B. H. Smith, of the U. S. Department of Agriculture, Bureau of Chemistry, Bulletin 91, 1907, has been adopted in the study of the mineral waters of Colorado by the Colorado Geological Survey.

Group	Class	Sub-class		
Thermal Non-Thermal	I. Alkaline	Carbonated or Bicarbonated	Sodic	Non-gaseous
		Borated	Lithic	Carbon-dioxated
		Silicated	Potassic	Sulphuretted
	II. Alkaline-saline	Sulphated	Calcic	Azotized
		Muriated	Magnesic	Carburetted
		Nitrated	Ferruginous	Oxygenated
	III. Saline	Sulphated	Aluminic	
		Muriated	Arsenic	
		Nitrated	Bromic	
	IV. Acid	Sulphated	Iodic	
		Muriated	Silicious	
			Boric	

Alkaline waters are (1) those which have an alkaline reaction and contain carbonic or bicarbonic acid ions in predominating quantities; (2) those which have an alkaline reaction and contain boric or silicic acid ions in predominating quantities, where it can be proved that the alkalinity is largely due to the presence of borates or silicates. The first class of alkaline waters is well known and is given in Peale's classification as constituting the whole class of alkaline waters. The second class of alkaline waters includes those which are more alkaline than can be accounted for by the carbonates or bicarbonates present, and contain predominating quantities of silicates or borates, which evidently cause this excess of alkalinity.

Saline waters are those which have an alkaline or neutral reaction and contain sulphuric, muriatic, or nitric acid ions in predominating quantities.

Alkaline-saline waters are between alkaline and saline. They embrace those which have an alkaline reaction and contain (1) sulphuric, muriatic, or nitric acid ions along with carbonic or bicarbonic acid ions, both classes being present as predominating constituents, or those which have an alkaline reaction and (2) contain sulphuric, muriatic, or nitric acid ions along with boric or silicic acid ions, both classes being present as predominating constituents, where it can be proved that the alkalinity is largely due to the presence of borates or silicates.

Acid waters are those which have an acid reaction, and contain either sulphuric or muriatic acid ions in predominating quantities.

The following paragraphs are copied from Mineral Springs of Canada, Part 1. The Radioactivity of Some Canadian Mineral Springs, by John Satterly and R. T. Elworthy, Canada Department of Mines, Mines Branch, Bull. 16 pp. 50-52, 1917.

THE THERAPEUTICS OF RADIOACTIVE WATERS

It may be interesting to outline the main results of investigations concerning the therapeutic value of radioactive waters, although the greater part of such work has been done using artificially prepared radioactive solution, usually many times more active than naturally found solutions.

In the first place an increased activity of all the processes of nutrition and metabolism occurs. Increased oxidation is evidenced by a rise in the percentage of all urinary solids other than the chlorides, and a considerable multiplication of the red blood cells has been often observed. Difference of opinion exists as to the question of the bactericidal effects of radium and its derivatives. Some authorities have denied any such effects, yet treatment at Bath has shown an antibacterial effect in the case of gonococci. Radium emanation certainly has power to stimulate the elimination of toxins.

Under the influence of radium emanation the insoluble sodium monourate can be changed into a soluble monourate, which subsequently decomposes into ammonia and carbon dioxide. Work upon patients whose blood contained uric acid has shown that a similar process takes place in the human body when treatment in an "emanatorium" is given.

The chief agent in the therapeutic use of waters is radium emanation.

There are five ways of absorbing emanation:

1. Through the lungs.
2. Through the digestive organs.

3. Through the skin.
4. Through the medium of different forms of injection.
5. Through the employment of local applications externally.

In the first case the chief source of the emanation would be the gases which are so often evolved from springs. These gases, passed into the air of a suitable room, constitute it an "inhalatorium".

The lung is the quickest medium of absorption and discharge, and the radium emanation dissolves in the blood to a certain extent. From the blood it can enter the organs and tissue cells. The most satisfactory condition will arrive when the blood is saturated with emanation.

The second method of absorption will be adopted when waters containing radium or emanation are drunk. In this way the emanation penetrates the stomach and intestines, and diffuses into the capillaries of the lymph and portal vein, and much of the emanation imbibed reaches the arterial blood. In the case of inhalation the emanation is much more rapidly absorbed, but it is retained only as long as it is breathed, while in the drink cure emanation is introduced into the system, and solid decomposition products are deposited, which will continue to send out the radiations which are the valuable agents.

In many cases, relatively strong radium solutions are injected into patients, though such treatment hardly comes within the province of natural water therapy.

Besides inhaling radioactive air, and drinking radioactive water, a variety of baths using radioactive water have been devised, though the question of absorption by the skin is a much discussed one. The majority of authors agree that emanation does not get into the organism through the skin, but it exclusively gets into the blood through the lungs.

However, others arguing on the grounds of their experience state that if baths are taken for sufficiently long time, considerable emanation is absorbed.

CLASSES OF WATERS

Under the broad classification of waters worked out by Haywood and Smith, the mineral waters of which complete analyses were made are grouped as:

Alkaline 55, Saline 47, Alkaline-Saline 106.

Of the 200 tested for radioactivity, 180 showed more than a "trace", and 13 are permanently radioactive. In the case of a large number of springs both the water and the accompanying gases were active. The deposits made by 43 springs were tested, and all but two were found to be radioactive, but only 12 were notably so.

NATIONAL PARKS AND MONUMENTS

Mesa Verde National Park

Southwestern Colorado stands preeminent in the United States as a place of archeological interest. The ruins of the Cliff Dwellers are widely scattered in the region about the common corners of Colorado, New Mexico, Arizona and Utah, but the center of interest is in the ruins of the side canyons of the Mancos River, which seem to have been the metropolitan area of these ancient pueblos.

In response to the solicitation of the club women of Colorado, Congress set aside an area of 50,000 acres for the preservation of these aboriginal ruins, and has provided funds for their exploration, study and educational use.

Though possessing none of the mountain features of the Rocky Mountain National Park, the Mesa Verde is by no means lacking in beauty. The general elevation of the Mesa is over 8,000 feet, and from its higher points only the limitations of the eye set a bound to the vision. North and west lies the Montezuma valley, dotted with reservoirs and fertile farms. To the north-east many miles distant are the Rico Mountains, and over the line in Utah several mountain groups may be seen.

The juniper, pinyon and other evergreen trees which forest the plateau and in many places occupy the canyon bottoms and gentler slopes suggested the name Mesa Verde.

The geological formations consist of a great book-like series of alternating sandstones, shales and occasional limestones in which nature has carved many ramifying canyons between mesa-like divides. The alternation of hard and soft strata has caused the development of canyon walls consisting of a succession of gentle slopes and steep, often vertical salients.

Unlike the canyon country farther north there is but little high coloring, so that the sculpturing is the main feature of attraction.

The vegetation is that of the arid and semi-arid regions, but there remains in the forested areas some evidence of a former greater precipitation, not only in the forest trees themselves, but the most convincing evidence of a change of climate is the fact that with the most primitive methods of cultivation the Cliff Dwellers made the region support a population greater than that which modern man with the best machinery could provide for from the same area without an extensive irrigation system.

The attractions of Mesa Verde National Park are *ruins*—archeologic rather than scenic. In these great ruins is preserved the history of a large primitive population which had passed through several cultural stages and had learned to use in a remarkably efficient manner the extremely limited gifts of nature.

Their architecture, the methods and products of their agriculture, their domestic arts—pottery, weaving, carving and the preparation of foods—their religion, superstitions and play are matters of study and interpretation by means of the well-protected ruins.

Good roads and trails lead to the best preserved and characteristic ruins. Guides and interpreters are ready to recite the story of these ancient peoples, not translated from clay tablets and carvings, but from the ruins of their cities, many of which were left as people would leave their homes for a journey or a visit.

The Hovenweep (Deserted Valley), National Monument, partly in Colorado and partly in Utah, was established to preserve four remarkable groups of ruins similar to those of the Mesa Verde National Park, yet having an individuality which adds much to the archeological interest of the Southwest.

The Wheeler National Monument is named for Captain George M. Wheeler, a noted pioneer engineer-explorer. It lies on the slope of the Continental Divide in the Rio Grande National Forest, near Wagon Wheel Gap on the Denver and Rio Grande Western. Its scenic beauty lies in the marvellous carving of soft volcanic beds into pinnacles, towers, buttes, capped spires and many fantastic forms, all of which are variously colored from pink to brown, yellow and white. Mazy winding canyons and defiles thread the forest of pinnacles and towers making a confusing labyrinth.

Rocky Mountain National Park

The people of the state and the nation gratefully remember the untiring efforts of Enos A. Mills which resulted in an act of Congress dedicating this mountain playground to health, recreation and education.

The Park consists of nearly 400 square miles of wonderfully diversified mountain country along the Front Range in Larimer, Grand and Boulder counties. To make its attractions easily accessible several highways have been built to the Park, and within its limits roads and trails lead to a wealth of grandeur and beauty which would provide the visitor new delights for many seasons.

Within the Park limits may be found every element which may contribute to natural grandeur and beauty.

Giant peaks present every angle of declivity, challenging the climber to exploration and adventure. Vantage points command limitless expanses diversified by ridge and valley, lake and stream, forest and meadow. In sheltered gorges and cirques on the high slopes lie snow and ice which have mocked the sun for centuries. Canyons, gorges, meadow-floored valleys, parks and glens await the lover of quiet beauty.

The scientifically inclined and studious will find the flower and tree, bird and insect, wild life of all kinds in new surroundings, rocks and minerals in new associations and roles in the processes of nature.

More than fifty peaks reach heights of 12,000 feet and over. Nearly 100 lakes are mapped and streams innumerable find their way to the plains below.

The vegetation ranges in character from that of the middle altitudes to the extreme alpine, and from the microscopic to the forest giant. The animal life is varied and abundant.

Descriptive names suggest the wealth of attractions. A few of these are: Deer Mountain, Bighorn Mountain, Bluebird Lake, Spruce Canyon, Lily Lake, Iceberg Lake, Specimen Peak, Chiefs Head, Tourmaline Lake, Fall River, Forest Canyon, Flattop Peak.

FISH AND GAME

Two-fifths of the area of the state, over 26,000,000 acres, is in the form of unoccupied Federal lands such as National Forests, National Parks and Monuments, lands withdrawn from entry for various purposes, and unappropriated and unreserved lands. Vacant state lands amounting to over 3,000,000 acres bring the grand total of unoccupied lands up to about 30,000,000 acres or 45 per cent of the area of the state.

Half the Federal lands are in the National Forests mainly in the mountainous areas of the state, and another very large area lies in the sparsely forested mountain regions adjoining the forests. The National Forests are set apart for the protection and growth of timber, and though they are open for recreation, sight-seeing and regulated cutting of timber, they are closed against permanent settlement.

Within these domains of the wild are thousands of lakes and streams, natural refuges without number, an abundance of food and climatic conditions of the most favorable character. The State has also established a great many game refuges within which at no time may any but predatory animals be killed.

The difficulty of traveling in the mountain areas except along the great highways is in itself a great protection to fish and game. To these conditions must be added the protection afforded by a well-organized Game and Fish Commission with its wardens placed at strategic points over the vast area, and the ever vigliant National Forest and National Park services all striving to protect and build up the fish and game resources of the state. This combination of conditions has already made Colorado a very attractive place for the sportsman and the lover of wild life, and the future promises even more than the present affords, both to the resident and to the tourist.

It is the belief of the Game and Fish Commission and the Forest Supervisors that the desirable forms of big game are increasing, under the protection afforded by the Forest Service and the Game Wardens, and the limited open seasons. The Forest Service census of game animals for 1925 gives the following approximate statistics: Black-tailed or mule deer, 22,868; white-tailed deer, 522; mountain sheep, 4,318; elk, 7,358; wolves, 75; coyotes, 25,585; black and brown bear, 2,783; lynx and wild cats, 6,167; foxes, 3,819; beaver, 47,314; muskrats, 21,135; marten, 8,010; mink, 5,860; badger, 4,299; and mountain lions, 505.

Mountain lions, wolves, bears, coyotes, lynx and wild cats are not protected by law and may be killed at any time.

The State Game and Fish Commission, realizing the great diversity of climate, food conditions, shelter and present distribution of wild life in the state, makes a careful study of local conditions and shapes its activities and methods accordingly, thereby rendering the best service possible, in view of the conditions to be met. This includes the introduction of foreign wild life and the grouping and distribution of the native forms in such a way as to produce the best results.

As a consequence, Colorado has now as great a variety of wild life as can be found anywhere in the country, and it is reasonable to expect such an abundance of game that greater privileges in the taking of game will become possible.

Among the game birds of the state are such natives as grouse, sage chickens, prairie chickens, wild turkeys and blue quail. Attempts have been made by the Commission to increase the numbers of some of these by breeding them in captivity, but so far only the turkey has proved responsive to this plan. Hungarian partridges, pheasants, the Bob White quail and other foreign birds have been introduced with gratifying success. Others are being tested, and efforts are being made to encourage the migratory birds to breed in the state.

Fur-bearing animals are increasing in numbers, and quite recently the establishment of fur farms particularly for the breeding of foxes has received considerable attention. Mink, skunk, muskrat, marten and others are being tried in captivity but up to the present without notable success.

The protection of insect-destroying birds has become an important activity, and is proving a great benefit to agriculture in all its branches.

The state has established a number of well equipped fish hatcheries having a total capacity of sixty million fry per year. Nurse ponds are provided so that the young fish may be placed in the streams and lakes at whatever age the conditions demand The mountain lakes and streams are stocked with trout of various kinds, but the plains lakes and reservoirs are supplied with bass, perch and croppies.

Chapter 11

CLIMATE AND SCENERY

CLIMATE

The climate of Colorado is one of her most valuable assets, whether it is considered from the standpoint of health, pleasure and comfort, or industry.

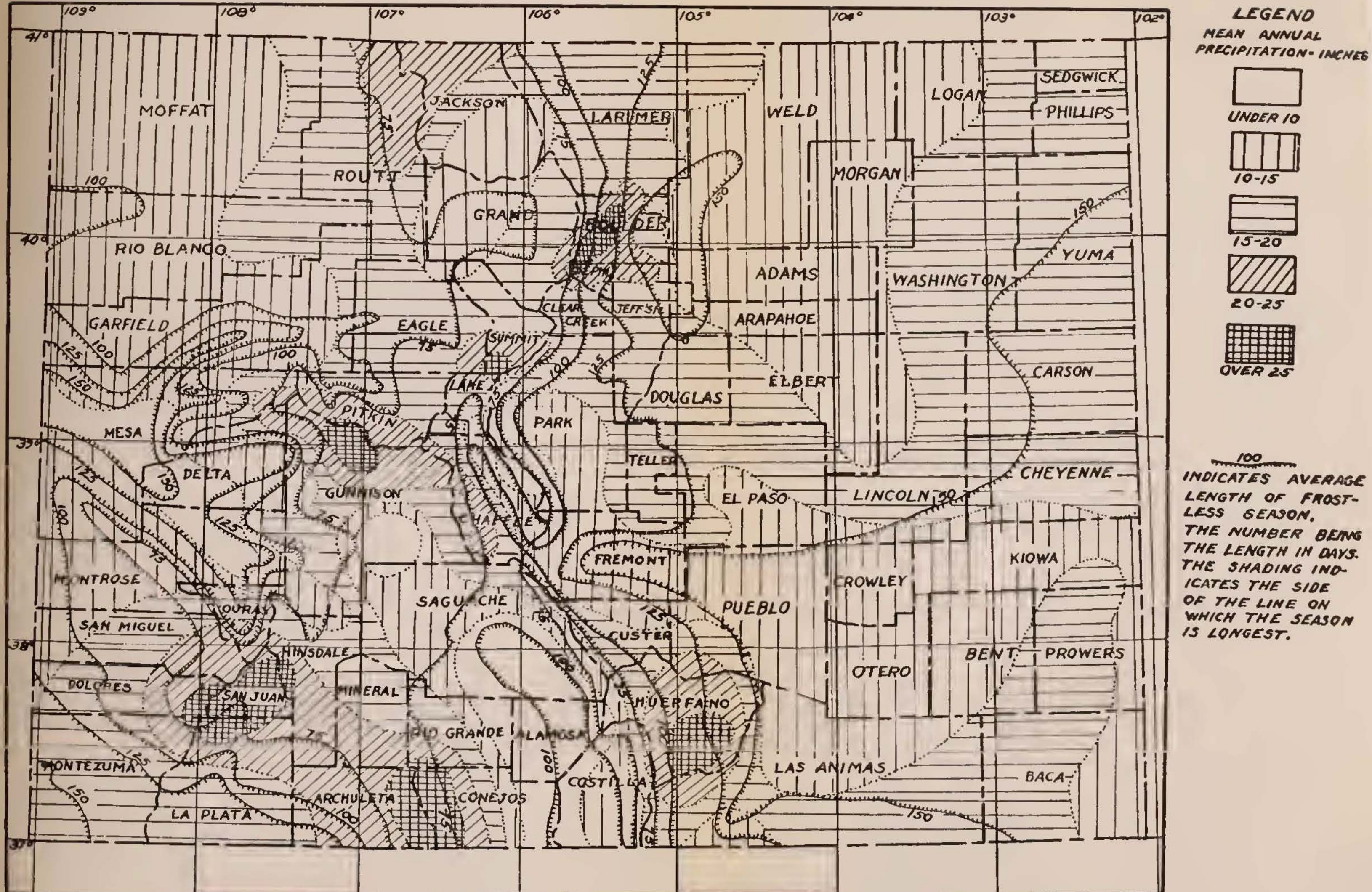
Climate is the average condition of the atmosphere, or briefly, the average weather over a long period. The elements of climate are: Temperature, including radiation; Moisture, including humidity, precipitation and cloudiness; Wind and storms; Pressure; Evaporation; Chemical, optical and electrical phenomena.

In spite of the wide variation in these elements of climate from place to place in the state, and from season to season in the same place, it is doubtful whether any other state of the Union has a climate so uniformly acceptable to the human system, and so conducive to health, comfort and bodily fitness.

So wide are the ranges in all the elements of climate that Colorado may be called a state of many climates. Yet running through all these local climates there is a harmonious combination and interrelation of the elements which give to all a common characteristic of buoyancy and exhilaration.

The weather, the basis of climate, is, at times, moody and fickle, but quickly returns to the sober yet ever welcome standard which we delight to call typical Colorado weather. What are the salient features of our climate? The temperatures are in the middle range without notable extremes in either direction. The relative humidity ranges between 50 and 60 per cent and, as a consequence, the extremes of temperature are comfortably borne. Perspiration is quickly evaporated, with a resulting sense of coolness, and the dryness of the winter air reduces the penetrating and chilling effect so trying in cold humid air. The high radiation rate and the generally cloudless sky result in a welcome cooling of summer air as evening falls.

The precipitation, though reaching its maximum in the late spring and summer months, is so distributed through the year that prolonged extremes of dryness and rain do not occur. Cloudiness is never depressing or long continued.



MEAN ANNUAL PRECIPITATION AND LENGTH OF FROSTLESS SEASON

DETERMINING FACTORS

It is very hard to present any general data as to the climate of Colorado on account of the great diversity of altitude and topography, both of which are important determining factors.

Nearly all the variations of a continental climate are to be found within the limits of Colorado. The controlling influences are:

1. Low latitude: A position south of the common track taken by storms.
2. Location: In the interior of the continent remote from the ocean.
3. Normal pressure distribution, especially with reference to the influence exerted by the winter high of the Great Basin whose place is taken during the warmer half of the year by an area of low pressure.
4. Altitude and diversified topography—features which greatly modify the effects of the low latitude and remoteness from the sea.

The position of the state half way between the Mexican and Canadian highlands to which the mountain zone gradually slopes, offsets in some degree the low temperature by which the high average altitude of the state would otherwise be characterized.

"The usual track of storms lies some distance to the northward, and the state is therefore generally in the southerly, the warm and dry, quadrants of the low areas that move eastward with great regularity, and escapes in part the attendant precipitation of moisture, the high wind movement, and the sharp fluctuations in temperature."

The slower movement of the northern low pressure areas in the summer months permits moisture from the Gulf of Mexico to reach the eastern side of the state and add to its rainfall.

In the winter the high-pressure area west of the range causes a flow of air as westerly winds over the divide down onto the eastern plains. In their descent they are warmed by compression and there prevails in the eastern half of the state a long succession of relatively dry, warm, and bright sunshiny days.

The low pressure west of the range in the summer causes a westward movement of the air from the eastern slope developing easterly winds which as they ascend are chilled and their moisture falls as rain in the summer months. This and the moisture from the Gulf combine to give eastern Colorado five-sevenths of its precipitation in the warmer half of the year.

The cold waves east of the range are generally thin strata of cold air originating far to the north and following the eastern front of the mountains until broken and dissipated to the southward.

The great diversity of altitude, causes a range of mean annual temperatures from 33° in the high districts to 54° in the lowlands.

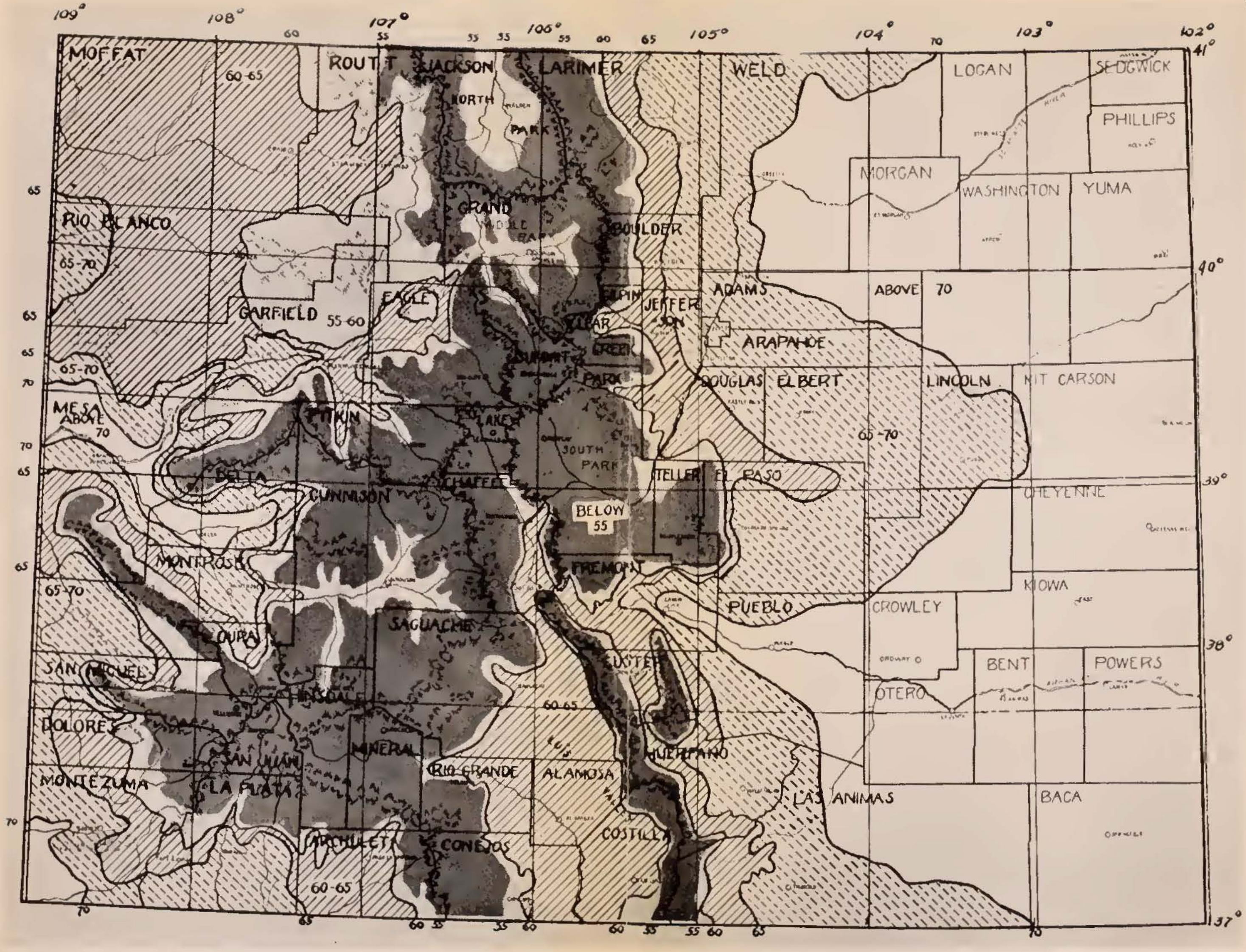
The amount and distribution of the rainfall depend upon location with reference to the high mountain masses, and the mean annual precipitation ranges from six inches in the driest areas to over 40 inches in the central mountain districts.

ZONES OF MEAN ANNUAL TEMPERATURE

1. Zone of 50° or higher: A small area in the valley of the Colorado and Gunnison; the valley of the Arkansas west to the foothills; the southeastern border counties; a narrow strip bordering on northwestern Kansas, and an area east of the foothills including Denver County and parts of Adams and Boulder counties.
2. Zone of 45° to 50°: The valleys of moderate elevation and the upland plains including the Arkansas-Platte divide, a narrow north and south belt parallel to the eastern foothills, the middle portions of the Colorado and Gunnison valleys, and the valley of the Las Animas.
3. Zone of 40° to 45°: San Luis Park, the foothills region, and the northwestern counties.
4. Zone of 35° to 40°: North, Middle, and South Parks, and generally the regions between 8,000 and 10,000 feet in elevation.
5. Zone of 35° and lower: The higher mountain areas, parts of the continental divide and the narrow valleys near the center of the state in Lake and Summit counties.

WINTER MEANS

The mean temperature of winter ranges from 35° at Canon City to 11° at Gunnison. For the southeastern counties the



MEAN SUMMER TEMPERATURES

Arkansas Valley, including Colorado Springs, and for a considerable area in the vicinity of Denver, the mean temperature is slightly above 30°, while the western valleys, the eastern foothills, the Arkansas-Platte divide, and the northeastern counties have means between 25° and 30°. The mean for San Luis Park is slightly above 20°. That of the North, Middle and South Parks and the higher mountain areas is below 20°.

SUMMER MEANS

The mean temperatures range from 76° in the lower part of the Arkansas Valley to 50° near the continental divide in Park County. Means of 70° and higher are common in the valleys of the eastern slope, and in the lower parts of Colorado and Gunnison valleys. San Luis Park has a mean of 63°, and slightly higher values are common in the northwestern counties. In the central mountain valleys the means are generally between 50° and 55°.

The map plate shows the mean summer temperature zones. The upper limit of the zone having a mean summer temperature of 70° and above follows closely the 5,000-foot contour line. That portion of the state lying between altitudes of 6,500 and 8,500 feet has a mean summer temperature between 60° and 65°F.

The decrease of temperature with increase of altitude averages between 3° and 4°F. per 1,000 feet for the months of March, April, May and June, and between 2° and 3°F. for the remaining months.

The difference between shade and sun temperature is very noticeable even at the lower altitudes in Colorado, and this difference increases with increase of altitude. At intermediate altitudes in Colorado the difference ranges from 30° to 50°F.

The absolute annual range of temperature in Colorado averages somewhat over 100°F.

The average daily range of temperature is generally between 25° and 29°, but in the mountain districts and in the northwestern counties they reach 30° to 38°.

The extremes of low and high temperature are of rare occurrence and are of short duration.

FROSTS

The map plate shows the length of the frostless growing season in various sections of the state. The table below gives the average dates of the last killing frost in the spring and the first in the fall, for a few important points:

	Last in Spring	First in Fall
Grand Junction	April 11	Oct. 28
Meeker	June 7	Sept. 12
Saguache	May 24	Sept. 17
Fort Collins	May 13	Sept. 21
Denver	May 7	Oct. 4
Pueblo	April 28	Oct. 25

RELATIVE HUMIDITY

The relative humidity is low and as a consequence the rate of evaporation from water surfaces or moist soil is high. On the plains areas of the state the average relative humidity ranges from 50 to 60 per cent. Along the eastern border of the state it averages about 60 per cent. Just east of the foothills it ranges between 48 and 50 per cent, and in the extreme western counties between 46 and 50 per cent.

SNOWFALL

The following table gives a few local averages, which may be regarded as indicative of general conditions:

	Inches
Arkansas Valley	21
San Luis Park	25
Grand and Uncompahgre Valleys	28
Eastern border counties	33
Arkansas-Platte divide	49
North-central counties	51
Southwestern counties (extreme)	81
South-central counties and eastern slope	96
Western slope of the continental divide	220

Along the higher part of the Front Range the relation between precipitation and melting is such as to cause the formation of glaciers.

CLOUDINESS

	Days
Clear days, average	181, or 50 per cent
Partly cloudy, average	119, or 33 per cent
Cloudy, average	65, or 17 per cent

VELOCITY OF WINDS, AVERAGE

	Miles per Hour
Grand Junction	5.2
Montrose	6.0
Pueblo	7.0
Denver	7.3
Las Animas	7.9
Northern and eastern borders	10.0

Winds of 40 miles per hour may be expected once per year at Grand Junction, ten times at Denver and fourteen times at Pueblo. They are principally from the west.

The average velocity of the winds is not high, but wind storms of short duration occasionally reach a high velocity, and thunder storms of the convection type characterize the summer precipitation, but are rarely attended by destructive falls of hail.

The pressure of the atmosphere upon the surface of the earth decreases as height above sea level increases. The table below gives the approximate pressure in pounds per square inch for different elevations:

Height above sea level, feet	Pressure in pounds
Sea level	14.7
5000	12.3
6000	11.8
7000	11.26
8000	10.85
9000	10.45
10000	10.06

The lower pressure upon the surface of the body appears to have an agreeable effect, and is particularly noticeable when first experienced.

The Rainfall

The rainfall ranges from 10 inches per year in the drier parts of southwestern Colorado to approximately 40 inches in the higher part of the mountain zone. In all parts of the state where soil, topography and the length of the season favor agriculture, the rainfall is very fortunately distributed. The months of heaviest rainfall are the growing months of May, June, July, August, and second to these are the fall months providing winter pasture.

In most of the agricultural areas of the state the manner of rainfall and the soil conditions are such as to favor the storage of the water in the tilth and uppermost subsoil where it becomes available for plant growth. By the adoption of now well known methods of working the soil the limited rainfall may be so husbanded as to make the so-called dry farming on our eastern and western plains a reasonably profitable industry.

The greater rainfall of the higher foothills and the mountain zone affords water for irrigation on the plains bordering the main streams.

CLIMATE AND HEALTH

Colorado offers "great fountains of health, in pure, dry, and stimulating air".

The influence of Colorado climate upon health and general well-being is both direct and indirect. The direct benefits come from abundance of sunshine with its health-giving and germ-destroying rays, the purity of the air, its low relative humidity, the delightfully acceptable mean temperatures, the stimulating daily range of temperature, the medium annual precipitation and the relatively low winter precipitation, and medium atmospheric pressure.

Much attention has been given to the healing effects of the direct rays of the sun carrying their full value unfiltered by cloud and artificial obstructions. Many bodily functions are quickened by direct sunlight, elimination is aided, germ propagation is retarded and many forms are killed by direct sunlight.

Extremes of temperature, especially in a humid atmosphere, are trying to health, and are the most favorable climatic inducements to colds, influenza, tuberculosis and rheumatism. Such extremes have the effect of keeping people indoors with windows closed and other means of ventilation checked. Impure air is breathed, normal bodily functions depending upon direct sunlight are slowed down, the natural resistance is reduced and susceptibility to disease is increased.

In higher altitudes the air is pure, respiration is increased and deepened and circulation is stimulated. Diseases affecting the lungs are especially benefited by these conditions.

The violet and ultra-violet rays of the sun have a very important effect upon certain bodily functions intimately connected with healing processes. They stimulate the production of red corpuscles improve metabolism, increase the capacity of the lungs for the absorption of oxygen, retard the propagation of certain putrefactive bacteria and are in many instances actually germicidal. They are especially beneficial in the cure of rickets.

The violet and ultra-violet rays are proportionately more abundant in the rare atmosphere of high altitudes, in dust-free air and in air of low relative humidity. Denser atmosphere, higher humidity and dust act as filtering agencies reducing the proportion of these rays, and consequently their effectiveness as healing agents. Air of low relative humidity permits a more perfect radiation and respiration from the surface of the body. The toxic waste is more readily eliminated and there is, in general, a more healthy functioning of the skin. Low humidity also retards bacterial activity and thus promotes the healing processes. High relative humidity just as certainly weakens resistance to disease.

The daily range of temperature of Colorado summer climate is a very valuable feature, not only because of the rest which the cooler night air affords but because of the stimulation of bodily functions by change and rest. There is nothing more depressing in climate than a dead level monotony of temperature, especially if it is accompanied by high relative humidity and grayness of light.

In regions of low relative humidity the winters are seasons of sudden and severe changes of weather which are fruitful causes of diseases which result from colds and chills, such as bronchitis, pneumonia, influenza, diphtheria and whooping cough. The sudden and severe changes lower the vitality, and weaken the resistance to the attack of disease germs. The tendency to these diseases is increased when people permit themselves to be driven indoors, neglect proper ventilation to insure a supply of fresh, pure air to meet the greater demands made upon the small space by the more constant occupancy and the greater number present.

In the agreeable, bracing winters of Colorado neither of these conditions is likely to play an important part. The love of fresh air and sunshine is a fixed habit, and the use of sleeping porches even in the winter is having a salutary and permanent influence upon the health of the people.

No more convincing argument as to the excellence of the climate of Colorado need be sought than the thousands, now enjoying perfect health, who came to Colorado as invalids.

The indirect benefits of Colorado climate arise from its irresistible call to an outdoor life in the pure air and the health-giving sunshine. Hiking, climbing, the playing of games almost force themselves upon young and old. Nature study—trees, flowers, birds, insects and other forms of wild life—has a fascination enhanced by the climate. It is easy to find "sermons in stones, books in the running brooks and good in everything."

The climate invites the cultivation of hobbies—gardening, photography, fishing, golf. These things have a most wholesome reflex action upon the mind and spirits. Business is forgotten. "The cares that infest the day" are left behind.

The outdoor life in Colorado re-creates, banishes meanness and moral miasma. It is health to body, mind and spirit.

COLORADO CLIMATE AND EFFICIENCY

The climate of Colorado is remarkably favorable to health, and it necessarily follows is equally favorable to physical and mental efficiency.

A variable climate is desirable if men are to be efficient either mentally or physically. Mean temperatures ranging around 35 to 45 for winter and 60 to 70 for summer, with daily fluctuations or ranges of 15 to 25 degrees in each season appear to be the nearest to the ideal for both mental and physical efficiency. In these respects Colorado is very favorably situated.

A comparison of the physical effectiveness of industrial labor in regions of high mean temperature, low mean temperature and intermediate mean temperature shows conclusively that, while a low mean is better than a high, intermediate mean temperatures are much the best. They permit sustained effort without excessive fatigue, and there is much less bodily waste which must be replaced by food if permanent depletion is to be avoided. A high mean temperature dulls the appetite and reduces the supply of energy through food, and depletion follows. A low mean temperature stimulates the appetite for certain foods. This reacts in sluggishness, drowsiness and physical inefficiency. The intermediate mean temperatures such as those of Colorado make for the highest average physical fitness and efficiency.

Industries in Colorado would be characterized by a high average labor efficiency if not deliberately held in check.

The effect of climate upon mental activity is very similar to that on physical fitness, and Colorado's mental worker is remarkably favored so far as climate is concerned. Students should show a higher average attainment in relation to age especially in the secondary schools and the colleges. Sustained mental effort in business pursuits should be attended with less fatigue.

All these conditions cooperate to maintain health of body and mind, mental and physical efficiency and longevity.

It is not difficult to see the operation of these climatic influences in our population in spite of the great handicap under which it has been placed owing to the very large percentage of the population made by those who came to the state seeking health, and the offspring of the health seekers.

SCENERY

One of the earlier writers on the attractions of the state described her scenery as: "Great fountains of natural beauty", and went on, "She may proudly bid the Nation come to her for strength — — — for vigor, for rest and restoration."

The Arkansas River crosses the state line at an elevation of 3,340 feet, the lowest point in the state. The summit of Mt. Massive is 14,420 feet above the sea. The maximum difference of elevation, therefore, is over 11,000 feet. Between these two extremes nature has laid formation upon formation, building a vast pyramid of rock of every kind, texture and color at her command. On the slopes of this structure she has carved forms innumerable—delicate, beautiful, vast, awe-inspiring. She has clothed them with forests, shrubs, grasses and many-colored flowers —"has sown these slopes with verdure, planted them with island groves and hedged them round with forest." Here and there, left open to view, stands the richly-colored living rock dappled with somber lichens. Upon this background she has laid a tracery of silver streams broken by falls and cascades. Within the deep green of the forests she has set emerald and sapphire lakes. Snow and ice add silvery tiaras to many of the higher peaks. Over this masterpiece of form and color is hung a canopy of purest blue, white-flecked with drifting clouds.

Limpid blue above thee bends
Like a sapphire sea,
Cloudy sails speed phantom ships
To their distant quay.

To locate the most attractive scenery of Colorado would be more than an artist's task. A hundred might choose and every one select a different combination of form, color and light. To some, size would be the master appeal, to others expanse. A complex harmony of form, color and light would meet the mood of today, while over-whelming grandeur would be the demand of tomorrow. A massing of diverse elements of scenery within small scope such as cliff, gorge, lake, glacier and stream would create the perfect picture for many. The forms from which arose the graceful Gothic arch, the massive Norman tower, and the slender minaret may inspire and satisfy. Some would find their highest satisfaction in beautifully sculptured slopes with "woods over woods in gay theatric pride"—all these and many more types of scenery oft repeated may be found within our six-fold Switzerland.

If the tourist is impressed by massive forms he should visit such great isolated peaks and mountain groups as Longs, Pikes, Sierra Blanca (Blanca and Old Baldy), the Collegiate Range (Harvard, Yale and Princeton), Ouray, Wilson and Holy Cross. Among the greatest expanses of tumultuously rugged scenery are the surroundings of Torrey and Evans, along the Front Range, Eolus and Sunlight in the Needle Mountains, and Handies in the San Juan. From Massive, Elbert or Lincoln may be seen the great mountain complex formed by the convergence of the Sawatch and Park ranges. In western Colorado south of the Colorado River are large areas occupied by the Cutler and Dolores formations. By reason of their great variety of material, their varying degrees of resistance to erosion, their brilliant and yet varied coloring, these formations have made possible the development of one of the scenic fairy-lands in this country. Steep-walled canyons of brilliant but always harmonious coloring, benches and shelves, spires and turrets, glens and caverns, tree-crowned cliffs and grassy basins abound in a startlingly beautiful though but little known part of the state.

The Colorado National Monument in Mesa County near Grand Junction was formed to preserve and make accessible to the public one of the choicest and most picturesque of these western canyon areas. These canyons are miniatures of the Grand Canyon in Arizona, on the same Colorado River drainage.

A somewhat similar canyon-cut country occurs in the southeastern part of the state, particularly in eastern Las Animas, and Baca counties. Many of these canyons are beauty spots well worthy of a visit.

The seventeen National Forests of Colorado cover one-fifth of the state, or about 20,000 square miles. As these forests are mainly in the mountain zone, they include much of the grandest scenery of the state as well as the best fishing and hunting grounds.

The Forest Service is much more than the name implies. The natural scenery is protected and made accessible by excellent roads and well built, clearly marked trails; camp sites are indicated, springs developed, and every reasonable facility is afforded the local visitor and the tourist for making use of the forests for recreation and health.

Provision is made by which lovers of the wild seclusion of the forests may secure long term leases on sites for permanent summer camps and cabins, and be assured of the protection of their property and rights.

The Forest Service also cooperates with the State Fish and Game Commission in the stocking of streams and lakes with fish, and in the protection of fish and game.

In every National Forest the lover of nature, the seeker after health and recreation, and the more scientifically inclined will find features of absorbing interest. Only a few of these can be referred to in a discussion so brief as this must be. The great mountain highways lead through open valleys and canyons now forested with pine, spruce and aspen, now hemmed in by many-colored rocks in crags, towers and vertical walls, offering little encouragement to tree, shrub or flower.

The road yields to the whim of the stream which is now on one side, now on the other, but ever busy making and unmaking the valley floor. Its changing moods pass in quick succession —plunging over cliffs, rushing through gorges, breaking into foam over bouldery rapids, subsiding into smooth, deep flow between grassy banks or widening into a placid lakelet. Overhead a strip of sky is framed by towering peaks, precipitous rock walls, craggy slopes and ledges.

The pass is reached and there is spread out below the observer a panorama of indescribable variety, beauty and grandeur. Amazement, awe, delight and inspiration by turns possess the soul "while the eye takes in the encircling vastness."

A few of the many attractions in the forests may be mentioned. In the Arapahoe are Grand and Monarch lakes. Grand Lake, the largest natural body of water in the state, lies at an elevation of 8,369 feet in mountain surroundings of great beauty. Park View Peak in the Rabbit Ears Range commands a view of North and Middle Parks. Specimen Mountain is an unusual attraction for the collector of minerals and rocks.

Summer sun and winter snow
'Mong the peaks contend,
And to vale and plains below
Flower and harvest send.

The Battlement Mesa Forest possesses an endless variety of scenery, but perhaps the most interesting is the tableland of Grand Mesa, with its hundreds of well-stocked lakes, its great forests and its glaciated surfaces.

In the Cochetopa Forest is Shavano Peak with the Angel of Shavano outlined in spotless snow in one of its high valleys. Ouray and San Luis peaks are among the isolated giants of the state.

The Colorado Forest claims the largest and most active of the glaciers—Arapahoe, Fair and Isabelle. Hundreds of lakes lie in ice-carved basins along the higher slopes of the Front Range, which reaches its maximum elevation in this forest.

Tints that mock the painter's art
Dim the vales and hills,
Songs too subtle far for words
Float above the rills.

Within the Gunnison Forest are several partially isolated ranges and mountain groups such as the West Elk, the Ruby and Storm ranges. The Gunnison River is one of the noted trout streams of the continent. The Black Canyon of the Gunnison with Curecanti Needle standing as a sentinel at its entrance is one of the most picturesque and awe-inspiring of the many canyons in the state.

The Leadville and Pike National Forests stand unrivalled for their great mountain ranges and for the number and height of their more isolated peaks. Elbert and Massive are the highest mountains in Colorado.

Granite peaks defiant stand
Limned against the blue,
Sculptured by the hand of time
Since the earth was new.

Diadems of silv'ry snow
On their summits gleam;
Clouds of rainbow-tinted spray
Shroud the mountain stream.

The western of the Twin Lakes is in the Leadville Forest. These lakes have been a popular resort for many years. Among the many mineral and hot springs in or on the borders of these forests are Cottonwood, Hortense, Princeton, Manitou, Strontia and Deckers.

No mountain area of the state excels that of the Durango Forest, which includes the La Plata, the San Juan and the Needle ranges. Good roads bring the tourist into the bewildering labyrinth of rocks and canyons carved from many colored rocks.

The Montezuma Forest presents two very distinct topographic areas. The east side is ruggedly mountainous, but the west is a plateau cut by a maze of canyons. In the east are such pinnacles as Lizard Head, Lone Cone and Ophir Needles; and highly-colored peaks such as Red, Calico and Vermilion. In the west are uncounted miles of canyons cut into flat-lying, highly-colored sandstones.

Holy Cross, Snowmass, and Sopris peaks, the Hanging Lake near Glenwood Springs, Independence Pass, and the Canyon of the Eagle River, are attractions of the Holy Cross National Forest. Snowmass Lake is one of the beauty spots of the state.

Fastnesses untrod by man
Ancient secrets hold,
Rock-rimmed lakes of regal blue
Mirror summits bold.

Berthoud and Independence passes are reached by magnificent highways through scenery of absorbing interest.

A large part of the wonderful scenery of the "Golden San Juan" lies within the San Juan National Forest. The awe-inspiring canyons of the Animas River led the Spanish explorers to name the stream Rio de las Animas Perdidas—River of Lost Souls. Pinkerton and Trimble Hot Springs are on the Animas banks. This forest abounds in canyons, gorges, mountain streams, cascades and rapids.

Among the many great mountains of the San Juan Forest are Pagosa, Windom, Eolus, Sultan and Engineer.

The Wagon Wheel Gap Hot Springs, and Wheeler National Monument are in the Rio Grande National Forest. The canyons of the Rio Grande and Conejos; the San Luis, Rio Grande Pyramid, and Bristol Head peaks, and Wolf Creek Pass are other notable features of this forest.

In the Routt National Forest are Rabbit Ears Pass, Welba and Bears Ears peaks and many parks and glades of appealing beauty. Steamboat Springs are at the town of Steamboat Springs just outside the forest lines.

San Isabel National Forest includes the magnificent Sangre de Cristo (Blood of Christ) Range, so named by the Spanish explorers on account of the brilliant sunset effects on the snowy crest lines of the range, through which there are only two passes lower than 10,000 feet.

*Long the priestly couriers
Of the Cross and Spain,
Struggled o'er the mountain steeps
And the arid plain.

*A group of missionary priests sent by the King of Spain to possess the cities of Cebolla, discouraged, and doubting the outcome of their mission, camped on the plains facing the great snow-capped range, as yet unnamed. Sunset enveloped the peaks in a crimson glow which they hailed as a divinely sent symbol of the crucifixion, and exclaimed, "Sangre de Cristo! El nos conduce y nos manda que sigamos abalante!" (Blood of Christ! He leads us and commands us forward.)

Doubting, toilworn, by a stream
Heavily they rest
As the haze-wrapped autumn sun
Sinks into the west.

Sunset crowns the snowy peaks
With a crimson glow,
"Blood of Christ! He captains us,
Forward bids us go!"

A large portion of the San Juan range with its snowy summits and precipitous slopes abounding in canyons and cascading streams lies in the Uncompahgre National Forest. In the center of the mountain area is the city of Ouray at which are remarkable canyons and highly-colored mountain slopes. Perhaps the most notable scenic highway of the state serves this part of the forest. From the commanding outlook of Uncompahgre Peak one may see stretched out before him parts of Colorado, Utah, Arizona and New Mexico.

Trappers Lake and its surroundings are widely known for their beauty and for their excellent fishing and hunting. The White River National Forest has many other areas of quiet beauty and charm.

Hayden National Forest takes in the northern limits of the Park Range in Colorado.

The La Sal National Forest includes but a few miles of Colorado territory without special scenic features.

Glaciers

In Pleistocene time (Glacial Period) glaciers and their contributing snowfields probably covered, almost connectedly, a strip several miles wide along the crests of the ranges having peaks 12,000 feet or over in height. Alpine glaciers extended from this capping mass down the valleys to levels ranging between 6,500 and 8,000 feet. The many cirques, (amphitheatre-shaped valleys) along the ranges, the smoothed and polished rock surfaces, the extensive morainal ridges in the valleys and on the lower divides, the ice-gouged lake basins, the moraine-formed basins, and the smoothed valley walls, are abundant and convincing evidence of the widely extended glaciation of the mountain zone of the state.

There are many perennial snow and ice banks in the high mountain areas of the state, but only those are glaciers which, by reason of a seasonal accumulation in excess of the waste by thawing, are set in motion outward or downward to a point where the waste exceeds the accumulation. If this test be applied it is evident that there have been discovered only a few glaciers in Colorado, though the name has been applied to many bodies of ice and snow. However, there are vast areas of our high mountain regions in which further exploration may result in the discovery of glaciers.

Along the high slopes of the Front Range in Boulder County south of the Rocky Mountain National Park are Arapahoe Glacier on Arapahoe Peak, Isabelle Glacier on Navajo Peak and the two St. Vrain glaciers at the head of the valley between Ogalalla Peak on the north and an unnamed peak on the south. Across the divide from Isabelle Glacier is Fair Glacier in Grand County.

In Laramie county within the National Park are several bodies of ice and snow which are commonly called glaciers. These are Taylor, Andrews, Tyndall, Sprague and Hallett, some of which are known to be moving, and as no one, by the eye alone, can detect the movement of a glacier, their scenic value to the majority will be equal to that of glaciers. Small glaciers have been found on Blanca, and they are said to exist on Massive.

The glacier region of the Front Range is one of the most attractive in the state apart altogether from the glaciers themselves. An array of outstanding peaks of great height with precipitous slopes both east and west, scores of beautiful lakes discharging their waters by cascading streams through rocky gorges to meadow and forest channels, a wealth of forest and flowers, make a scene of grandeur and beauty rarely surpassed.

In this area one may study glacial phenomena of the past and the present—an illustrated lecture course.

Hell Hole, a gorge almost unrivalled for rugged sculpture, lies a short distance from Arapahoe Glacier on the Grand County side of the divide.

Speeding day her mountain throne
Leaves with backward gaze,
Threading purple, rose and gold
Through the falling haze.

Evening lifts her magic wand
Peaks are aureoled,
Purple haze of mazy depth
Wooded slopes enfold.

Appendix

THE PRINCIPAL ORES OF COLORADO

GOLD ORES

Gold is found native in the many placers of the state and in many of the mines of the great sulphide belt, especially in their upper workings. But the most important source of the metal has been the tellurides which in many mines occur with the native gold, but in others, especially in the unweathered parts of the veins, occur alone. The native gold of much of the shallow workings has been formed by the alteration of the telluride.

Cripple Creek, the most important gold camp of the state, has produced only tellurides except from the weathered upper parts of the veins.

Calaverite is a telluride carrying about 40 per cent of gold, and a little silver. It occurs as embedded grains, as crusts of matted crystals, and granular masses of silver white to pale yellow color and brilliant luster. It is very brittle and forms a dark gray powder.

Krennerite has approximately the same color, luster and composition, but differs in crystal form.

Sylvanite is almost indistinguishable from calaverite except by quantitative analysis, which shows that it contains about 2 of gold to 1 of silver.

Petzite is a telluride of gold and silver, having a metallic luster and steel-gray to iron-black color. It occurs with other tellurides in several Boulder County mines and in one or two at Cripple Creek.

Pyrite, galena, sphalerite and arsenopyrite, and other sulphides, are carriers of native gold in many Colorado mines. Of these, pyrite is much the most important.

SILVER ORES

Silver occurs in many forms, some of which are the most important in one area, but may be rare in others. Native silver is found in the oxidized or weathered portions of many veins, where it occurs as "wire," "moss" and "plate," as an alteration product from the primary minerals.

CERARGYRITE, (horn silver, silver chloride) is soft, waxy encrusting mass varying in color from gray to yellowish-gray, to brownish and greenish-gray. Occasionally it retains the form of the minerals from which it is formed. It contains 73.3 per cent of silver, and occurs with native silver and other alteration products in the upper workings of mines.

ARGENTITE, the sulphide, is a soft lead-gray or blackish mineral of dull luster occurring as crusts, coatings and solid masses. It forms cubes and octahedrons sometimes connected by wires of native silver. It contains 87.1 per cent of the metal.

PYRARGYRITE, dark ruby silver, is a sulphantimonide carrying 60 per cent of silver. It is commonly deep red and translucent, but is sometimes black and opaque. It associates with other silver ores and occurs in masses sometimes showing crystal faces.

PROUSTITE, light ruby silver, (65.4 per cent silver) differs from pyrargyrite in containing arsenic instead of antimony. It is scarlet-vermilion, translucent, soft, and has a rather brilliant luster when freshly broken. It is a common ore in the San Juan and in the Ruby mining district of Gunnison County.

STEPHANITE, brittle silver, (68.5 per cent silver), is an iron-black, soft, brittle mineral of metallic luster occurring in masses and scattered grains with other silver ores and lead ores.

POLYBASITE is a sulphantimonite of silver, of iron-black to reddish-black color and metallic luster, and carrying 75.6 per cent silver and a little copper. It is most common in the Telluride and Rico mines and in Clear Creek.

TETRAHEDRITE and TENNANTITE are essentially copper minerals, but in Colorado are commonly silver-bearing and in places are important ores of silver carrying as high as 20 to 30 per cent of silver.

GALENA is very commonly silver-bearing, and in many mines is the principal ore of silver.

HESSITE is a telluride of silver carrying 63 per cent silver and a little gold. It is rather soft, slightly sectile and has a rather dull metallic luster and occurs in a few Boulder mines, and rarely elsewhere in the sulphide belt.

SILVER-BEARING GOLD TELLURIDES are described under gold minerals.

CHALCOPYRITE, PYRITE, CHALCOCITE and other copper minerals are quite commonly silver-bearing.

LEAD ORES

The important ores of lead are galena, cerussite and anglesite. Aikinite, cosalite and hinsdalite are found in the San Juan, occasionally in commercial quantities. Mimetite was fairly abundant in the upper workings of several Leadville mines.

Phosgenite is a commercial ore in the Terrible mine at Ilse.

GALENA is the sulphide of lead and carries 86.6 per cent of lead and very commonly considerable silver. It is a pure lead-gray mineral having a brilliant metallic luster, a perfect cubical cleavage and a hardness of 2.5. It is readily crushed to a black sub-lustrous powder. In open places it crystallizes in cubic forms, "cog lead," sometimes showing octahedral faces. It is far the most important ore of lead in Colorado, and contributes in an important way to the silver production.

CERUSSITE is the carbonate of lead, carries 77.5 per cent of lead. It is generally white to gray, but may be yellowish, bluish, or grayish-black. It has a bright luster, inclining to resinous, is very brittle, and is readily distinguished from other common carbonates by its weight. It occurs as granular and sandy masses, "sand carbonate," and in solid seams or veinlets, and capping and coating galena from which it is derived. It was an important ore in the upper workings of many lead mines, and for years was the important ore of Leadville. It is frequently silver-bearing.

MIMETITE, a chlorarsenate of lead carrying 69.5 per cent of lead. It is pale yellow to brown or orange, very brittle, and when fresh has a resinous luster. It frequently occurs as a dull yellow powder. It is an alteration product from other ores.

ANGLESITE, lead sulphate, carries 68.3 per cent lead. It is a colorless to white to yellowish gray mineral, which when fresh has a beautiful glossy to resinous luster. It is comparatively soft, and is very brittle. It occurs overlying and coating galena, from which it is formed by weathering.

AIKINITE is a blackish-gray sulphide lead ore carrying 36.2 per cent bismuth, 36.0 per cent lead and 11.0 per cent copper. It is soft, brittle, and has a metallic luster. Locally, it occurred in sufficient quantity in the La Plata area to be an important source of bismuth—a fact which the operators did not recognize in time to profit by it. It may carry silver.

COSALITE is similar to aikinite but carries higher percentages of lead and bismuth. It may also carry silver and copper. It might have been an important source of bismuth in the La Plata mines, if recognized in time.

HINSDALITE is a comparatively rare lead ore occurring in the Lake City mines of Henson Creek. It is a hydrous sulphate and phosphate of lead and aluminum. It is colorless to greenish-gray and commonly occurs as a coarsely crystalline mass with many cleavage faces.

JAMESONITE occurs as an ore in a few places in Colorado but is nowhere important.

PHOSGENITE closely resembles cerussite and differs from it in composition by the presence of chlorine, and in its crystalline forms. It occurs with and alters to cerussite.

ZINC ORES

Zinc ores are very widely distributed in Colorado, but in the early days of mining in the state were of no economic value, and were in reality a great hindrance to the recovery of the other metals both in the mines and in treatment processes. The metal zinc was not then in so great demand and the metallurgy of the sulphide of zinc had not been worked out. The principal ores are sphalerite, Smithsonite and calamine. Hetaerolite and the sulphate goslarite contributed in a small way to the zinc production.

SPHALERITE, the sulphide, zinc 67 per cent, is a mineral of many colors and lusters, and many zinc sulphides contain iron, manganese and cadmium. Perhaps the commonest colors are yellow, black, steel-gray and red. The luster is commonly resinous, and the mineral may be transparent, translucent or opaque. It shows good cleavage and is brittle. In open spaces, it forms crystal faces.

SMITHSONITE, the carbonate is formed by the weathering of the sulphide, and is common in the upper workings of the Leadville and other mines especially where the ores are associated with limestone. The color ranges from colorless to gray, white, greenish, brownish and pale blue. It is vitreous to dull and earthy in luster, and may be transparent, but is generally opaque or translucent. It carries 52 per cent zinc.

CALAMINE, the silicate, contains 54 per cent of zinc. It occurs as an alteration product from the sulphide and is found in the weathered portions of the mines. It also occurs as a primary mineral, but not in commercial quantity in Colorado.

HETAEROLITE, a hydrous oxide of zinc and manganese, occurring in a few mines in the Leadville area, as an alteration product from the sulphide. It is dark brown to black and has a sub-metallic luster resembling a varnish. It is generally opaque.

GOSLARITE was formed in considerable quantity in the abandoned workings and about the dumps formed in the days when zinc was a nuisance to the operators. It is a hydrous sulphate of zinc of white to yellowish color, translucent to transparent.

TIN ORES

Tin has not been found in commercial quantity in Colorado.

CASSITERITE is found in scattered grains in acidic granites along the Front Range and elsewhere. The color is remarkably variable, but black to iron-gray and brownish-red are common colors. It is very fine textured and breaks with a smooth to uneven fracture.

ALUMINUM ores have not been found in commercial quantity in the state. A little *bauxite* and a little *cryolite* have been found.

The former was probably developed from highly aluminous clays by the action of hot springs. It is a soft, earthy, whitish to yellowish and red mineral, breaking with a smooth fracture. It carries 35 to 45 per cent of aluminum, depending upon the degree of hydration.

Cryolite is found in the vicinity of St. Peters Dome but the amount is too small to attract attention. It is a fluoride of sodium and aluminum, of vitreous to pearly luster, irregular fracture, but as a rule, somewhat hard to break.

COPPER ORES

Very few ore deposits in Colorado have been worked for copper as their chief product. By far the largest part of the copper produced has come from the ores of the sulphide belt whose chief values lay in gold, silver, lead and zinc.

The Independence mine at Apex, the Cashin and Cliffdweller mines near LaSalle Creek, a branch of the Dolores, and a few other small properties are the only recent exceptions.

The copper-bearing ores of the sulphide belt include copper-bearing pyrite, chalcopyrite, chalcocite, tennantite, tetrahedrite (gray copper) enargite, bornite, covellite and the carbonates azurite and malachite.

CHALCOPYRITE is a copper-iron sulphide, carrying when pure, 34.5 per cent of copper. It is a brass-yellow, soft, lustrous brittle mineral which crushes to a black or grayish-black powder and on heating yields a strong sulphur odor and gives a green color to the flame. It is a common accompaniment of the other metallic sulphides.

CHALCOCITE is the sulphide of copper and carries 79.8 per cent of copper. It is a lustrous black to bluish black mineral which breaks with a smooth conchoidal fracture. It also occurs as a soft, sooty powder, enveloping sulphides containing copper and is an alteration product from them.

TENNANTITE and TETRAHEDRITE (gray copper) are very similar in appearance and can rarely be distinguished without chemical tests. They are dark gray to iron-black, have a brilliant metallic (sub-silvery) luster, a smooth to fine granular fracture. The tennantite is a sulpharsenite. The tetrahedrite is a sulphantimonite. Both carry silver.

FREIBERGITE is a name given to argentiferous tetrahedrite. It is probable that tennantite bearing silver is more common than tetrahedrite in Colorado.

ENARGITE is a sulpharsenate of copper containing 48.3 per cent of the metal. It is a grayish-black to iron-black faintly lustrous, rather soft mineral, commonly showing distinct cleavage and sometimes a sub-fibrous structure. It breaks with an uneven fracture and good cleavage. It is characteristic of many of the deep workings along the sulphide belt, but is nowhere a very important constituent of the ores.

BORNITE is a copper-iron sulphide carrying 55.5 per cent of copper. It is remarkably variable in color—from copper-red to pinchbeck-brown, and tarnishes to iridescent surfaces. The luster is metallic, the fracture small and brittle, the powdered mineral is grayish black.

COVELLITE is cupric sulphide carrying 66.4 per cent of copper. It is a lustrous indigo to navy blue color, and is commonly tarnished. Platy forms are common, and good cleavages show on fresh surfaces. It occurs sparingly along the sulphide belt, but is found in considerable quantity in the mines of LaSalle Creek near the Dolores River.

AZURITE, the blue carbonate, and MALACHITE, the green carbonate, occur as alteration products in the weathered upper portions of ore bodies. They carry respectively 55 per cent and 57.4 per cent copper. Only rarely have they been found in minable quantity. They are brittle, commonly fibrous or botryoidal and form crusts over the minerals from which they are formed.

URANIUM AND VANADIUM ORES

Uranium occurs in the form of two very distinct minerals—pitchblende or uraninite and carnotite. The first of these is found near Central City, the second is widely distributed in western Colorado.

PITCHBLENDE is a very complex mineral and sometimes contains as many as 12 to 15 elements but the principal contents so far as value is concerned, are uranium oxide and radium. The mineral is gray to olive-green to dark brown and has a rather dull or subdued pitchy, resinous luster from which it has received its name. It breaks with a fairly smooth fracture, is brittle and easily powdered, is quite hard, and very heavy—nearly 10 times as heavy as an equal volume of water.

CARNOTITE is really a vanadate of uranium and potassium, carrying 60 per cent of uranium oxide, 20 per cent of vanadium oxide, and 6.6 per cent of potassium oxide. It is a canary yellow powder composed largely of minute crystals, sometimes massed into amorphous looking crusts, nodules and thin seams. In the mining area the mineral is found fairly pure in places, but in many localities it is associated with various vanadium minerals which may give it a color ranging from yellowish-brown to grayish-brown and greenish-yellow and nearly black, depending upon the percentage of carnotite present.

PATRONITE, the sulphide of vanadium, is a dark green, amorphous mineral containing 25.5 per cent of vanadium. It has been reported from several places in the carnotite area of western Colorado, but absolute proof of its occurrence has not been found.

HEWETTITE and METAHEWETTITE, hydrous calcium vanadates, are deep red silky, fibrous minerals usually forming crusts in seams and over the surfaces of rock fragments and other minerals. They easily melt to a dark red liquid. On exposure they darken and crumble.

TORBERNITE is a copper uranite containing 61 per cent of uranium oxide. It forms crystalline scales and crusts in seams in the sandstones in which carnotite is found. The color ranges from golden to green.

VANOXITE is a dark colored vanadium oxide which probably causes the mottled appearance of much of the western uranium-vanadium ores.

ROSCOELITE is a complex micaceous silicate containing potassium, vanadium, magnesium, iron and aluminum. It is a brownish-green to olive-green flaky mineral of pearly to earthy luster, very soft and generally faintly translucent.

TUNGSTEN ORES

The tungsten ore of the main Boulder area is ferberite. Near Ward and in the San Juan Hubnerite is the principal ore. A little scheelite occurs in all the areas, but is nowhere a commercial ore.

FERBERITE is a lustrous black to blue-black tungstate of iron carrying, when pure, 76.32 per cent of tungstic oxide. Thin plates are weakly translucent, and the powdered mineral has a brownish tinge. One cleavage is good, and the mineral is very easily powdered. Wedge or chisel-shaped crystals are frequently formed as crusts over rock surfaces.

HUBNERITE is essentially a tungstate of manganese, of seal brown color, fine cleavage and silky to sub-metallic luster. It crumbles easily to a hair-brown powder. Tabular and prismatic crystals are common, in radiating bunches.

SCHLEELITE is a calcium tungstate carrying 80 per cent of tungsten trioxide. The color ranges from colorless to yellowish-gray, brown and green. The luster is glassy and the mineral is translucent to transparent. It has a fair cleavage, is brittle and breaks with an uneven fracture.

MOLYBDENUM

Molybdenite is the principal ore of the metal, but in the upper and weathered portions of the deposits molybdite or molybdic ocher occurs as an alteration product.

MOLYBDENITE is the sulphide of molybdenum and carries 60.0 per cent of the metal. It is a soft lead-gray, sectile, mineral of metallic luster, commonly crystallized in flexible flakes, or short, six-sided prismatic crystals. It is so soft that it may be used as a crayon. The mark is like that of graphite.

MOLYBDITE is a yellow ocherous, hydrous oxide of molybdenum and iron resulting from the alteration of the sulphide. It occurs as a powder, perhaps composed of hair-like crystals, of dull luster, and very soft. It is rarely in vein-like masses.

MANGANESE ORES

Manganese ores seldom consist of a single mineral, but are generally mixtures of various oxides and hydroxides. The carbonate and the silicate and manganiferous siderite are the primary minerals and the others are products of alteration. It is probable that manganiferous siderite is the parent ore of the Leadville, Red Cliff and other ores. Only the more important oxides are described.

PYROLUSITE is the dioxide (and polianite has the same composition). The color is black to dead steel-gray to bluish-black and the luster metallic to sub-metallic, and earthy when the mineral occurs as a powder. Radiating masses of fibrous crystals forming botryoidal crusts and seam-fillings are common. The crystallized mineral has one or two good cleavages.

PSILOMELANE is a black to gray hydrous manganese oxide, usually containing about 39.5 per cent of the metal. It has a sub-metallic to earthy luster, is never crystallized, and gives a brownish-black shining streak. It occurs in amorphous masses which take on a rounded or kidney-shape. It is often interlayered with pyrolusite.

MANGANITE is a hydrous oxide of manganese (62.4 per cent of the metal), which forms felty masses of crystals, frequently found in radial arrangement. The luster is more metallic than that of the preceding ores.

RHODOCHROSITE is a rhombohedral carbonate of manganese containing 47.7 per cent of the metal. The color ranges from rose to brownish red, the luster is vitreous, cleavage perfect, and the mineral is transparent to translucent.

RHODONITE is the silicate and is probably the primary source of all the other minerals of manganese. It is a dense, hard pinkish to white mineral which associates with the rock-making silicates.

IRON ORES

The ores of iron are too well known to need more than a brief description.

MAGNETITE carries 72.4 per cent of iron. It is the most widespread of the ores, but ranks third in importance as an ore. It is black, is attracted by the magnet. It is commonly titaniferous, and this makes it hard to smelt.

HEMATITE is an oxide of iron and contains 70 per cent of the metal. It occurs as a red and as a black mineral both of which give a red powder when crushed. A variety rarely occurring as an ore is micaceous, has a brilliant luster and is slightly magnetic. Hematite is the favorite ore of iron, and is usually the purest.

LIMONITE may be called hydrous hematite. It is rarely a pure mineral of definite composition, but is generally a mixture of three hydrous oxides—limonite, goethite and turgite. The iron content is about 60 per cent as it occurs. It is not crystallized. The streak is yellow to brown. It has been the chief iron ore of Colorado. The Orient deposit was almost entirely limonite.

SIDERITE, the carbonate of iron, is very widely distributed as a gangue mineral in the metalliferous veins of the state, but does not occur in mining quantity.

Manganese-bearing siderite is probably the parent or primary mineral of the largest manganese deposits of the state—the manganiferous iron ores and the manganiferous silver ores of the Leadville part of the sulphide belt.

ILMENITE is an oxide of iron and titanium in which the two metals occur in the ratio of 36.8 to 31.6. Titanium may come into use again in the steel industry, but at present its chief use is in the paint industry.

TANTALUM ORE

There is a steady demand for tantalum and it is probable that Colorado may be able to help meet it.

The principal ore is tantalite but it is rarely found pure. Columbium is generally present and in many cases practically displaces the tantalum. The mineral is then called columbite-tantalite.

Tantalite is black to iron-gray to seal-brown, is very heavy, breaks with a sub-conchoidal to uneven fracture which has a sub-metallic to metallic luster. It should be sought in pegmatite veins with feldspar, mica, beryl, and associated minerals.

The mixed mineral occurs in several places in the state and there is reason to believe that tantalite carrying the oxide of tantalum in commercial quantity may yet be found in the pre-Cambrian area of the state.

Alphabetical Index

Many formation names do not appear in their alphabetical order, but practically all are grouped under the word "Formations."

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