Map Series 28

Location Map and Descriptions of Metal Occurrences in Colorado with Notes on Economic Potential

◆ Descriptions ◆

By
Randall K. Streufert
and
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Colorado Geological Survey
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Introduction

Nineteen ninety-three marks the 135-year anniversary of mining in Colorado. During this period the State has produced a large number of metallic elements from diverse mineral deposit types. This tradition continues to the present and, indeed, a significant portion of the State's economy continues to be tied to the development and exploitation of its metallic resource. The known metal deposits of Colorado have been widely studied and are well documented in the literature. Colorado's metallic resources, both in known deposits and in those not yet discovered, have an indicated potential to meet changing demands in world metal markets. Although many historic Colorado mining districts have been idle in recent years, ongoing research into metallogenesis of the State's deposits, coupled with recent exploration, insures that economically viable mining ventures will and continue to be developed as markets become available.

Plate 1 is a representation of currently known locations of selected metals in Colorado. Map entries are documented locations of metallic concentrations which are generally above crustal abundance for a particular metal. Map information is plotted either as a data point, representing a possible error of one square mile, or as a general area, or mining district, from which a number of metals have been produced. In addition, this document contains information on trace metals which may prove to be of economic importance in the future. Information on the distribution of trace metals whether in separate occurrences or that contained as a byproduct of the States's known metal deposits, is scarse. Hence, these potentially economic metals are not included on the map.

Locations of metals are based, in part, on information contained in the Colorado section of the Mineral Resource Data System (MRDS) data base, designed and maintained by the United States Geological Survey. This comprehensive resource information system covers the metallic commodities which have been important historically to the State's economy, as well as providing prospect information and site-specific data on lesser known deposits and mining districts from which modern production could be realized.

Table 1. Key to symbols

Ag	Silver
As	Arsenic
Au	Gold
Ba	Barium
Be	Beryllium
Bi	Bismuth
Ca	Calcium
Cd	Cadmium*
Co	Cobalt
Cr	Chromium*
Cs	Cesium*
Cu	Copper
Fe	Iron
Ga	Gallium*
Ge	Germanium*
Hf	Hafnium*
Hg	Mercury
In	Indium*
K	Potassium
Li	Lithium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
Nb/Ta	Niobium/Tantalum
Ni	Nickel

Pb	Lead
PGE	Platinum Group Elements
Rb	Rubidium*
Re	Rhenium*
REE	Rare-Earth Elements
Se	Selenium*
Sn	Tin
Sr	Strontium*
Th	Thorium
Ti	Titanium
Tl	Thallium*
W	Tungsten
Y	Yttrium
Zn	Zinc

* Not on Plate 1

Table 2. Pertinent mineral species.

Ag SILVER

Primary minerals:	
native silver	Ag
argentite	Ag_2S
proustite	Ag_3AsS_3
pyrargyrite	Ag_3SbS_3
stephanite	Ag_3SbS_4
pearceite	$Ag_{16}As_2S_{11}$
polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$
freibergite	$(Ag,Cu)_{12}(Sb,As)_4S_{13}$
strohmeyerite	CuAgS
sternbergite	$AgFe_2S_3$
miargyrite	$AgSbS_2$
matildite	$AgBiS_2$
aguilarite	Ag_4SeS
cerargyrite	AgCl
amalgam	AgHg
bromyrite	AgBr
iodyrite	AgI
dyscrasite	Ag_3Sb
empressite	Ag_5Te_3
hessite	Ag_2Te
sylvanite	$(Ag,Au)Te_2$
petzite	Ag_3AuTe_2
Host minerals:	
galena	PbS
cerussite	$PbCO_3$
angelsite	$PbSO_4$
tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$
tennantite	$(Cu,Fe)_{12}As_4S_{13}$
arsenopyrite	FeAsS
chalcocite	Cu_2S
enargite	Cu_3AsS_4
aikinite	$PbCuBiS_2$

As ARSENIC

native arsenic	As
arsenopyrite	FeAsS

Au GOLD

Primary minerals:	
native gold	Au
electrum	AuAg
gold amalgam	Au_2Hg_3
krennerite	$AuTe_2$
calaverite	$AuTe_2$
sylvanite	$(Ag,Au)Te_2$
petzite	Ag_3AuTe_2
Host minerals:	
pyrite	FeS_2
chalcopyrite	$CuFeS_2$
magnetite	Fe_3O_4
arsenopyrite	FeAsS
galena	PbS
cerussite	$PbCO_3$

Ba BARIUM

barite	$BaSO_4$

Be BERYLLIUM

beryl	$Be_3Al_2Si_6O_{18}$
bertrandite	$Be_4Si_2O_7(OH)_2$
euclase	$BeAlSiO_4(OH)$
chrysoberyl	$BeAl_2O_4$

Bi BISMUTH

native bismuth	Bi
bismuthinite	Bi_2S_3
aikinite	$PbCuBiS_2$
emplectite	$CuBiS_2$
beegerite	$Pb_6Bi_2S_9$
bismite	Bi_2O_3
bismutite	Bi_2CO_3

Ca CALCIUM

calcite	$CaCO_3$

Cd CADMIUM

Primary mineral:

greenockite	CdS

Host mineral:

sphalerite	ZnS

Co COBALT

cobaltite	$CoAsS$
skutterudite	$(Co,Ni)As_3$
erythrite	$Co_3(AsO_4)_2 \cdot 8H_2O$

Cr CHROMIUM

chromite	$FeCr_2O_4$

Cs CESIUM

Primary mineral:

pollucite	$H_2Cs_4Al_4(SiO_3)_9$

Host mineral:

lepidolite	$K(Li,Al)_3(Al,Si)_4O_{10}(F,OH)_2$

Cu COPPER

native copper	Cu
covellite	CuS
chalcocite	Cu_2S
chalcopyrite	$CuFeS_2$
bornite	Cu_5FeS_4
enargite	Cu_3AsS_4
polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$
tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$
tennantite	$(Cu,Fe)_{12}As_4S_{13}$
cuprite	Cu_2O
chalcanthite	$CuSO_4 \cdot 5H_2O$
rickardite	Cu_3Te_2
azurite	$Cu_3(CO_3)_2(OH)_2$
chrysocolla	$CuSiO_3 \cdot 2H_2O$

Fe IRON

pyrite	FeS_2
magnetite	Fe_3O_4
hematite	Fe_2O_3
goethite	$FeOOH$
siderite	$FeCO_3$

Ga GALLIUM

Host minerals:

gibbsite	$Al(OH)_3$
diaspore	$Al_2O_3 \cdot H_2O$
sphalerite	ZnS

Ge GERMANIUM

Host mineral:

sphalerite	ZnS

Hf HAFNIUM

Host mineral:

zircon	$ZrSiO_4$

Hg MERCURY

quicksilver	Hg
cinnabar	HgS
amalgam	$AgHg$
coloradoite	$HgTe$

In INDIUM

Host mineral:

sphalerite	ZnS

K POTASSIUM

sylvite	KCl

Li LITHIUM

spodumene	$LiAlSi_2O_6$
lepidolite	$K(Li,Al)_3(Si,Al)_4O_{10}(F,OH)_2$
amblygonite	$(Li,Na)Al(PO_4)(F,OH)$

Mn MANGANESE

alabandite	MnS
pyrolusite	MnO_2
hausmannite	Mn_3O_4
rhodochrosite	$MnCO_3$
rhodonite	$MnSiO_3$

Mo MOLYBDENUM

molybdenite	MoS_2
ferrimolybdite	$Fe_2(MoO_4)_3 \cdot 8H_2O$

Na SODIUM

halite	$NaCl$
nahcolite	$NaHCO_3$
dawsonite	$NaAl(OH)_2CO_3$
natron	$NaCO_3 \cdot 10H_2O$

Nb/Ta NIOBIUM/TANTALUM

columbite-tantalite	$(Fe,Mn)(Nb,Ta)_2O_6$
pyrochlore-microlite	$(Na,Ca)(Nb,Ta)_2O_6(O,OH,F)$
samarskite	$(Y,Ce,U,Ca,Pb)(Nb,Ta,Ti,Sn)_2O_6$
euxenite	$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$
fergusonite	$(Y,Er,Ce)(Nb,Ta)O_4$

Ni NICKEL

millerite	NiS
polydymite	Ni_3S_4
bravoite	$(Ni,Fe)S_2$
pentlandite	$(Fe,Ni)_9S_8$
niccolite	$NiAs$
skutterudite	$(Co,Ni)As_3$
melonite	$NiTe_2$

Pb LEAD

lead	Pb
galena	PbS
bournonite	$PbCuSbS_3$
boulangerite	$Pb_5Sb_4S_{11}$
aikinite	$PbCuBiS_2$
cosalite	$Pb_2Bi_2S_5$
beegerite	$Pb_6Bi_2S_9$
altaite	$PbTe$
cerussite	$PbCO_3$
angelsite	$PbSO_4$
minium	Pb_2O_4

PGE PLATINUM GROUP ELEMENTS

Primary minerals:	
native platinum	Pt
native paladium	Pd
Host mineral:	
chalcopyrite	$CuFeS_2$

Rb RUBIDIUM

Host minerals:	
lepidolite	$K(Li,Al)_3(Al,Si)_4O_{10}(F,OH)_2$
pollucite	$H_2Cs_4Al_4(SiO_3)_9$

Re RHENIUM

Host mineral:	
molybdenite	MoS_2

REE RARE-EARTH ELEMENTS

Primary minerals:	
monazite	$(Ce,La,Nd,Th)PO_4$
bastnaesite	$(Ce,La)(CO_3)F$
fluocerite	$(Ce,La,Nd)F_3$
synchisite	$(Ce,La)Ca(CO_3)_2F$
lanthanite	$(La,Ce)_2(CO_3)_3 \cdot 8H_2O$
samarskite	$(Y,Ce,U,Ca,Pb)(Nb,Ta,Ti,Sn)_2O_6$
euxenite	$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$
allanite	$(Ca,Ce,La,Th)_2(Al,Fe)_2(SiO_4)_3(OH)$
Host minerals:	
xenotime	$Y(PO_4)$

Sb ANTIMONY

Primary minerals:	
native antimony	Sb
stibnite	Sb_2S_3

Sn TIN

cassiterite	SnO_2

Sr STRONTIUM

Primary minerals:	
celestite	$SrSO_4$
strontianite	$SrCO_3$

Th THORIUM

Primary minerals:	
monazite	$(Ce,La,Nd,Th)PO_4$
thorite	$ThSiO_4$
thorogummite	(U,Th,Ce)SixOy
euxenite	$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$

samarskite	(Y,Er,Ce,U,Ca,Fe,Pb,Th)(Nb,Ta,Ti,Sn)$_2$O$_6$

Host mineral:

fergusonite	(Y,Er,Ce)(Nb,Ta)O$_4$

Ti TITANIUM

Primary minerals:

ilmenite	$FeTiO_3$
perovskite	$CaTiO_3$
rutile	TiO_2

Host mineral:

magnetite	Fe_3O_4

Tl THALLIUM

Host mineral:

sphalerite	ZnS

W TUNGSTEN

Primary minerals:

scheelite	$CaWO_4$
wolframite	$(Fe,Mn)WO_4$
powellite	$Ca(Mo,W)O_4$

Y YTTRIUM

Primary minerals:

bastnaesite	$(Ce,La)(CO_3)F$
xenotime	$Y(PO_4)$
monazite	$(Ce,La,Y,Th)(PO_4)$
fergusonite	$YNbO_4$
euxenite	$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$
gadolinite	$Be_2FeY_2Si_2O_{10}$

Zn ZINC

Primary minerals:

sphalerite	ZnS
smithsonite	$ZnCO_3$
hydrozincite	$Zn_5(CO_3)_2(OH)_6$
hemimorphite	$Zn_4Si_2O_{10}(OH)_2 \cdot H_2O$

Description of Metal Occurrences

Antimony (Sb)

Native antimony has been described from only one mining district, the Gold Hill district, Boulder County, where it occurs as minute crystals in some of the polymetallic sulfide and telluride ores. The antimony sulfide, stibnite, is a more common form of antimony, but is by no means abundant. Stibnite is a common accessory mineral in the extremely rich gold ores of the Cripple Creek mining district, Teller County, and is quite frequently very rich in gold itself due to admixed calaverite. Stibnite has also been mined for its gold content at the Alice Mine, Clear Creek County (Eckel, 1961).

Metallic antimony is typically recovered from primary stibnite ore, or as a byproduct of the smelting of precious/base metal ores, especially lead-silver ores. Colorado lead-silver ores commonly contain a number of antimony-bearing sulfosalts, of which the copper-antimony sulfide, tetrahedrite, is the most common. Many lead-silver ores are also rich in the silver-antimony sulfides, pyrargyrite or "ruby-silver", polybasite, and miargyrite. Past production records for antimony are obscure except for a 1943 report from San Juan County stating a production of less than 500 pounds (Dasch, 1968). It is likely that this figure does not represent total antimony production to date from Colorado.

More than one-half of the 1993 etimated domestic demand for antimony metal and oxides was derived from imported source material. Antimony utilization from domestic source materials was accomplished through the recycling of lead-antimony batteries, and to a lesser degree, as a recovered byproduct of the smelting of lead and silver-copper ores. In 1993, antimony was used in flame retardants (74%); transportation, inluding batteries (11%); chemicals (9%); ceramics and glass (2%); and other uses (4%) (U.S. Bureau of Mines, 1994).

Arsenic (As)

Elemental arsenic has been of little economic importance despite the fact that basic minerals of this element are widespread and locally abundant in some of the State's mining districts. There have been periods when arsenic was produced in Colorado as a by-product of the smelting of base metal ores. In 1920 the American Smelting and Refining Company reportedly produced 5000 pounds of arsenic at the Globe plant at Denver, recovered by the reprocessing of baghouse flume and flue dust from the lead smelters at Pueblo, Durango, and Leadville. Arsenic, in those days, was used in the manufacture of now obsolete insecticides prepared from calcium and lead arsenate compounds. A cotton boll weevil epidemic in the southern United States in the latter portion of the 1920s placed a high demand on arsenic, stimulating Colorado to be ranked third in the nation in the production of arsenic in the years 1928 and 1929 (Dasch, 1968). There is, however, no modern production of this commodity from Colorado.

Native arsenic is extremely rare, having been described only in some of the ores of the Leadville district, Lake County (Eckel, 1961). The predominant arsenic source mineral, arsenopyrite, is a fairly common constituent in hydrothermal vein deposits but has been valuable only as a host lattice for gold and silver. Another important mineral of arsenic, the arsenic sulfosalt, tennantite, has been mined for its frequent precious metal values but probably has not been a source of elemental arsenic.

United States domestic usage of arsenic in 1992 was as follows: wood preservatives (66%); agricultural chemicals (23%); glass (4%); nonferrous alloys (4%); and other uses (3%) (US Bureau of Mines, 1993a).

Barium (Ba)

The economics of barium are essentially identical to that of the source mineral barite. Barite is common in many of the State's mining districts, occurring as a gangue mineral associated with deposits of silver and base metals. Barite is abundant as a gangue mineral in silver veins at Creede, Mineral County, and in low temperature barite-silver-minor base metal replacement ores at Leadville, Lake County (Thompson and Arehart, 1990). Barite also occurs as a gangue mineral elsewhere in the State. In the Silver Cliff and Rosita mining districts of Custer County, barite has been mined as a primary commodity from mono-minerallic veins up to 4 feet wide. Barite has not been produced in Colorado for a number of years (Eckel, 1961).

The economics of barite are dependent on world oil prices. Up to 90 percent of the current demand for this commodity is for use as a weighting agent in drilling fluids, the demand for which increases when domestic oil well drilling activity is strong. Decreasing petroleum prices resulted in lower domestic rig counts in 1993 from that recorded in 1992. This was offset in 1993 somewhat by an increase in demand for natural gas which boosted rig counts slightly and, consequently, the demand for barite. United States import for consumption of less expensive foreign barite just exceeded domestic production, almost all of which was supplied from mines in Nevada and Georgia. Major import sources are China, India, and Mexico. Other 1993 domestic end uses of barite were in the manufacture of paint, rubber, glass, and barium chemicals (10%) (U.S. Bureau of Mines, 1994).

Beryllium (Be)

Beryllium minerals are fairly abundant in Colorado, and have been recovered both as a byproduct of the mining of feldspar-mica pegmatites, and from vein deposits. The vein deposits have been the most important economically. Beryllium has not been produced commercially in Colorado for a number of decades.

Beryl is the predominant ore mineral of beryllium. Veins of beryl, occurring with wolframite, cassiterite, topaz, and some galena, have been mined in the Badger Flats area of Park County. The Badger Flats area, at one time, was the largest producing beryllium district in the United States and was thought to contain the largest apparent reserve. Large deposits of bertrandite developed at Spor Mountain, Utah, are now regarded to house the largest domestic reserve of beryllium.

Beryl has also been produced as a vein mineral in the Brown's Canyon district, Chaffee County, occurring with sericite, molybdenite, ferrimolybdite, and fluorite, in massive milky white quartz. The Park County deposits are Precambrian in age, while those in Chaffee County are Tertiary (Griffitts, 1968). These mining districts are unique in that beryl was mined from high-grade beryllium hydrothermal vein deposits, unlike other Colorado districts in which beryllium minerals were mined as accessories from pegmatites. The majority of beryllium recovered to date has come from these mining districts.

The best regarded North American locality for fine euhedral crystals of bertrandite is the Mount Antero deposit in Chaffee County. This pegmatite deposit is also known for the gem quality aquamarines found there. Crystals of both of these beryllium silicates are found in miarolitic vugs in pegmatite bodies of the Mount Princeton batholith, high on the upper slopes of Mount Antero and White Mountain (Eckel, 1961).

The Saint Peter's Dome area of El Paso County contains interesting veins of beryl and fine-grained bertrandite associated with minerals of niobium, thorium, fluorine, and the rare earths (Griffitts, 1968). The district has not posted much production but is known for mineral specimens.

The element beryllium is important in electronics and as a strategic alloy metal for aerospace and defence applications. However, recent cut-backs in defence procurements have adversely effected beryllium metal prices. Beryllium alloys enjoyed some growth in 1993 due to increased demand for beryllium-copper strip in computer application, and from increased uses of berllium-copper alloy in undersea fiber optics telecommunications systems. Domestic consumption in 1993 consisted of: use as an alloy metal or as an oxide in the manufacture of electronics components (52%); as an alloy, oxide, and metal in the aerospace and defence industries (17%); as an alloy and oxide in electrical components (18%); and other (13%). (U.S. Bureau of Mines, 1994).

Bismuth (Bi)

The primary occurrences of bismuth in Colorado are as the native element, or more commonly, as the sulfide bismuthinite. The mixed sulfides aikinite, a lead-copper-bismuth sulfide; emplectite, a copper-bismuth sulfide; and beegerite, a lead-bismuth sulfide are known and have most likely contributed to the production of bismuth. All of these species are reported from mining districts throughout the state as primary vein minerals (Eckel, 1961).

Silver-bismuth veins in the southern half of the Montezuma mining district, Park, Summit, and Clear Creek Counties, are rich in primary bismuthinite. Unusually deep oxidation of these deposits has produced appreciable quantities of a secondary alteration product, bismite, a bismuth oxide, which stains the ore a "canary yellow" color (Lovering, 1935). In the Clear Creek (Winfield) district of Chaffee County, bismuthinite associated with native bismuth is commonly rich in silver. Bismuthinite, associated with argentite as microscopic inclusions in galena, is common at Leadville, Lake County, in both primary and secondary ores (Eckel, 1961). Bismuthinite occurrences in some of the state's pegmatite districts are generally of a lesser grade. Bismutite, a carbonate of bismuth, is commonly present as an oxidation product of primary bismuth minerals in many mines and has probably accounted for some of the production.

Bismuth has rarely been mined as a primary commodity, but rather has been recovered as a byproduct from the processing of lead-silver ores. Virtually all of the State's recorded production of bismuth was realized during the years 1900–1912, when Colorado led the nation in the production of bismuth. In 1901, 318 short tons of bismuth ore were shipped from mines in Lake and Ouray Counties. The American Smelting and Refining Company recovered considerable bismuth from lead bullion received from the Leadville smelter in 1915 (Dasch, 1968). There has not been production of bismuth from Colorado in recent times.

Bismuth has become of interest worldwide in the past few years due to its suitability as a non-toxic substitute for lead in chemical and metallurgical applications. The most potentially significant development is on-going research into the substitution of bismuth for lead in plumbing fixtures. If this research proves successful and this substitution is widely observed, current world supplies would have to be doubled to meet a minimum projected demand (U.S. Bureau of Mines, 1993a). Domestic consumption of bismuth in 1993 consisted of: pharmaceuticals and chemicals (52%); metallurgical additives (26%); fusable alloys and solder (20%); and other uses (2%) (U.S. Bureau of Mines, 1994).

Cadmium (Cd)

Descriptions of cadmium in Colorado to date have been of the cadmium sulfide, greenockite, which occurs as a surface coating on the zinc sulfide mineral, sphalerite.

Greenockite has been documented in only a few mining districts. Because the cadmium atom is similiar in size to the zinc atom, it can freely substitutes into sphalerite, a very abundant mineral statewide.

Although some cadmium has been recovered as a byproduct from polymetallic ores during smelting, it has probably not had an appreciable dollar value. The American Smelting and Refining Company produced cadmium at its Globe Plant near Denver beginning in 1910. The source was most likely zinc-bearing ores from the Leadville district, Lake County, and from flue dust, dross, and other byproduct material received from various smelters in operation around the state at that time (Dasch, 1968). Ore currently mined at Asarco's Blackcloud Mine, Leadville district, Lake County, contains cadmium as the only trace metal (Thompson, pers. comm., 1993). In 1992, cadmium was produced in Colorado through recovery from imported byproducts, including lead smelter baghouse dust.

Domestic usage of cadmium in 1993 was as follows: batteries (55%); coatings and platings (14%); pigments (16%); plastics and synthetic products (10%); and alloys and as other (5%) (U.S. Bureau of Mines, 1994).

Calcium (Ca)

Calcium is widespread in the earth's crust and is a constituent of most common rock-forming minerals, such as calcite, gypsum, and plagioclase feldspar. Only a few rocks which contain significant amounts of calcium are mined as industrial mineral commodities or construction materials.

Limestone is mined at several localities in the state for uses in cement manufacture, agricultural fillers, aggregate, and as a feed stock for the chemical industry. Marble is mined as a dimension stone at the historic Yule Marble Quarry near Marble in Gunnison County. The Mississippian Leadville Limestone and the Cretaceous Niobrara Formation are the most common sources of high quality limestone.

Gypsum and anhydrite occur widely through the state as a common accessory mineral in sedimentary rocks. They occur in massive quantities in Pennsylvanian rocks such as the Eagle Valley Evaporite in the Eagle basin and the Paradox Formation in the Paradox basin. Gypsum is used, primarily, in the fabrication of wallboard. A total of 280,000 tons of gypsum was produced in 1992 from an open pit mine in Eagle County.

Cesium (Cs)

Cesium is the most electropositive and the rarest of the five naturally occurring alkali metals. The metal occurs in pegmatite deposits as the hydrous cesium aluminum silicate, pollucite, or in the lithium mica, lepidolite. Cesium is normally recovered as a coproduct of the processing of ores of beryllium, titanium and lithium (U.S. Bureau of Mines, 1993b).

Cesium has not been produced in Colorado and there have been no reported occurrences of pollucite to date. Colorado has produced lithium and beryllium from a few important pegmatite districts and the eventual discovery of cesium minerals in some of these pegmatite deposits is a possibility. Lepidolite has been produced in the Gold Brick district, Gunnison County, but the presence of cesium has not been documented in these ores.

There is currently no important market for cesium, however, research into the use of this alkali metal in electronic, photoelectric, and medical applications may have a bearing on future markets. The small quantities used domestically for research and development were supplied from lepidolite ores processed in Canada (U.S. Bureau of Mines, 1993a).

Chromium (Cr)

Chromium is a common trace element in igneous rocks, predominantly in mafic and ultramafic rocks. Mafic and ultramafic rocks as a whole are rare in Colorado and significant concentrations of chromium are unknown. No production of chromium is reported to date from Colorado.

The principle ore mineral of chromium is the iron-chromium-oxide, chromite. A report of chromite on Mount Silverheels in Park County has never been confirmed (Eckel, 1961).

There is currently no domestic production of chromium from primary ore. In 1993 and for the sixth year consecutively, the United States carried a net import reliance in the 75 percent range, with the remaining 25 percent or so of chromium demand being supplied through the recycling of stainless steel scrap. Domestic end use consumption of chromium in 1993 consisted of: stainless and heat-resisting steel (80%); full-alloy steel (7%); superalloys (2%); and other (11%) (U.S. Bureau of Mines, 1994).

Cobalt (Co)

The few cobalt rich deposits known in Colorado have been little more than mineralogic curiosities. In the unusual nickel deposits of the Gold Hill district, Boulder County, the cobalt arsenic sulfide, cobaltite, is found in veinlets which cut earlier polydymite veins. Skutterudite, an arsenic mineral which contains cobalt and nickel, and the secondary mineral, erythrite, or "cobalt bloom", are reported from the Elk Mountains of Gunnison County, in the vicinity of White Rock Mountain. Erythrite is also reported from San Miguel County where it occurs as a secondary mineral in a vein of mixed sulfides and molybdenite near Placerville (Eckel, 1961). This hydrated alteration product of primary cobalt minerals is used as a guide mineral in the exploration for cobalt.

No primary cobalt production is attributable to the United States for 1993. Domestic consumption consisted of superalloys used in aerospace applications (42%); magnetic alloys (10%); catalysts (15%); paint driers (11%); cemented carbides (8%); and other (14%) (U.S. Bureau of Mines, 1994).

Copper (Cu)

Copper has not been mined as a primary commodity in Colorado but has been recovered as a secondary product from the processing of base metal sulfide ores mined primarily for gold and silver. Smelter payments for base metals from Colorado's polymetallic ores have historically been greater for their lead and zinc contents than for copper. The copper that has been produced has mostly come from the iron copper sulfide mineral, chalcopyrite, which is a common constituent of many metallic ore deposits and is frequently rich in gold. Some recovered copper is attributable to other copper sulfides, copper sulfantimonides, and copper sulfarsenides, also mined for their precious metal content.

Native copper occurs in many mining districts as a secondary mineral from the oxidation of primary copper minerals but has not been of economic importance. Native copper found in iron hydroxide-rich bog deposits in the Montezuma mining district, Summit and Park Counties, was precipitated from iron sulfate rich waters by the action of bacteria in organic matter. A 150 pound mass of native copper was mined at the Excelsior Mine, Lake City district, Hinsdale County,(Eckel, 1961).

The simple sulfides of copper, covellite and chalcocite, are not widespread but do occur in the zone of secondary enrichment in some polymetallic deposits. Covellite, rich in silver and associated with chalcocite, bornite, native copper, cuprite, azurite, and malachite was mined at the Cashin Mine in Montrose County. In the Summitville district, Rio Grande County, covellite is an abundant secondary mineral occurring in large aggregates of euhedral bladed crystals.

Chalcopyrite has been of economic importance in Colorado due to the large amounts of gold which can be hosted in this mineral in solid solution or as minute inclusions in micro-fractures. The gold content of ores from mining districts statewide is repeatedly proven to be hosted in chalcopyrite.

The platinum group metals (platinum and paladium) which occur in the Allard stock in the La Plata mining district, La Plata County, are hosted in disseminated chalcopyrite in an alkalic intrusive.

Other copper minerals, notably the copper sulfantimonide-sulfarsenide series, tetrahedrite-tennantite, or gray copper minerals, have been important as host minerals for both gold and silver and have probably supplied minor amounts of copper. Rickardite and weissite, both tellurides of copper, were first described in ores from the Vulcan and Good Hope Mines of Gunnison County (Eckel, 1961).

United States domestic mine production of copper in 1993 was at an all time high of 1.8 million tons, valued at about $4.1 billion. United States net import reliance for copper has been steadily decreasing in recent years through 1991 when the United States became a net exporter of refined copper. In 1992 and 1993, domestic net import reliance slipped back to 2 percent and 6 percent respectively. This is due to increased production from new and expanded primary copper mines in Chile, and also from a small loss of 1993 U.S. productions attributable to heavy rains in the first part of the year which diluted leach solutions at solvent extraction/elctrowinning operations. Domestic usage of copper and copper alloy for 1993 was as follows: building construction (42%); electrical and electronic products (24%); industrial machinery and equipment (13%); transportation (11%); and consumer and general products (10%) (U.S. Bureau of Mines, 1994).

Gallium (Ga)

Gallium occurs in extremely low concentrations in the earth's crust and is recovered mainly as a byproduct from the processing of bauxite ores and zinc ores (U.S. Bureau of Mines, 1993b). This element has not been recovered from ores mined in Colorado to date.

The non-mineral term, "bauxite", refers to a group of hydrous aluminum oxide minerals, usually gibbsite, boehmite, and diaspore, which are mined as the primary ores of aluminum. Colorado does not possess the climate required for the formation of these minerals, which normally occur in warm humid areas characterized by lateritic soils. A reported bauxite occurrence in the Buena Vista area, Chaffe County, is poorly substantiated. Diaspore and gibbsite have been reported from Custer County and San Juan County respectively, occurring most likely as weathering products of alunite in volcanic rocks (Eckel, 1961). These mineral occurrences are minor and do not indicate potential for the commercial recovery of gallium from Colorado bauxite ores.

Colorado is, however, rich in zinc and the potential for recovery of gallium from the state's abundant zinc sulfide (sphalerite) ores deserves future investigation. Primary gallium is not presently recovered from any domestic mining operation, but was produced from zinc ores of the Tri-State mining district and from iron oxide minerals in Utah as late as 1990 (U.S. Bureau of Mines, 1993a).

In recent years gallium has come into demand due to its utilization in the synthesized material, gallium arsenide (GaAs), which has evolved from a laboratory curiosity into an advanced material used in a number of "high-tech" applications. Gallium in its metallic form is of little commercial use. Gallium arsenide is a semiconducting compound and is rapidly replacing silicon in many electronic devices. This compound also possesses photovoltaic capabilities, allowing it to convert electrical energy to optical energy or the reverse, rendering it useful in light-emiting-diodes (LEDs), laser diodes, photodiodes, and solar cells (Kramer, 1988). United States consumption of gallium in 1993 consisted of: gallium arsenide components (93%); research and development and alloys (7%) (U.S. Bureau of Mines, 1994).

Germanium (Ge)

Germanium is a hard, very brittle, semiconducting element with electrical properties between those of a metal and those of an insulator. Because of this property, the element has important application in solid-state electronics in the manufacturing of transistors. Like gallium, this element is recovered as a byproduct of the smelting of zinc ores. Germanium is not currently recovered from Colorado zinc ores, but may have been in the past, as this commodity has been in general use since the 1950s (U.S. Bureau of Mines, 1993b).

Many Colorado mining districts are enriched in zinc minerals, specifically the zinc sulfide, sphalerite, indicating a need for research into future potential for their exploitation as a possible source of germanium and other rare metals. For a summary of the state's zinc resource the reader is referred to the zinc section of this document.

Germanium-rich residue is recovered at present at a zinc smelter in Clarksville, Tennessee, from domestic zinc ores. Cessation of zinc mining in the Tri-State district has drastically reduced the available domestic supply of this commodity. Small amounts of germanium were recovered from iron oxide minerals at a mine in Utah during the years 1986–1987 (Foster, 1991). Domestic end-uses of germanium for 1993 were: infrared optics (25%); fiber-optic systems (35%); detectors (10%); and catalysts, phosphors, metallurgy, and chemotherapy) (20%); and semiconductors (10%) (U.S. Bureau of Mines, 1994).

Gold (Au)

Gold ranks second only to that of molybdenum in the total dollar value realized to date from the mining of metals in Colorado. Indeed, Colorado's mining era began with the discovery, in 1858, of placer gold in streams in the vicinity of modern-day Denver and shortly thereafter in the streams of the Front Range of the Rocky Mountains. As the search for gold increased statewide, other metallic elements were discovered and exploited for economic gain. Close behind the wave of gold seekers came the permanent settlement and cultural development of Colorado. No other single metallic element possesses the ability to fire the imagination or to create the impetus for a tide of civilization as does gold.

Of the estimated 42 million plus ounces of gold produced to date, close to half has probably been in the form of native gold (Davis and Streufert, 1990). This has come either from placer deposits or as free gold in hydrothermal veins, stockworks, and replacement deposits. Colorado has produced remarkable specimens of native gold, some of which have been discovered in recent years. The fabulous wire and leaf gold specimens found at Farncomb Hill, Breckenridge district, Summit County, are no less inspiring today than when they were mined in the late 1800s. In the summer of 1990, the second largest gold nugget discovered in Colorado, weighing 8 oz troy, was found at the Pennsylvania Mountain placer in Park County (Parker, 1992). These specimens are all currently on display at the Denver Museum of Natural History.

Next in importance for gold production are the telluride minerals, many of which were first named and described from Colorado localities. Ores rich in the gold telluride minerals commonly return astronomical assay values and have accounted for a large percentage of total production. The Cripple Creek district of Teller County is a world class telluride district and holds the distinction of having produced 21,000,000 ounces of gold, close to half of the State's total. Assay values from the Gold Hill telluride district, Boulder County, have run as high as 1000 ounces per ton.

Another important source of gold has been abundant base metal sulfide minerals, many of which are ubiquitous to mining districts statewide, and possess the ability to host gold in solid solution or as inclusions in microfractures. The iron and iron-copper sulfides, pyrite and chalcopyrite, are the most common of the gold-rich sulfide minerals, but gold has also been identified as a constituent of other base metal sulfides and in the iron oxides, magnetite and limonite.

Gold deposit locations and types are widespread and diverse. The reader is referred to Davis and Streufert (1990) for a full description and analysis of Colorado's gold resource.

In 1993, Colorado gold production amounted to 154,000 ounces, up from an estimated 1992 production of 120,000 ounces. Battle Mountain Gold Company's San Luis Gold Mine, Costilla County, produced 72,000 ounces from low-grade bulk mineable pyritic ore, compared to 56,000 ounces reported for 1992. The remainder of 1993 gold production was as a byproduct of lead-zinc mining at the Black Cloud Mine operated by Asarco Inc.; Pikes Peak Mining Company, with operations in the historic Cripple Creek district; and through the processing of waste material from the historic Central City district, Gilpin County, by Solution Gold Inc.

United States domestic use of gold for 1993 was as follows: jewelry and arts (70%); industrial (mainly electronic) (23%); and dental (7%) (U.S. Bureau of Mines, 1994).

Hafnium (Hf)

Hafnium occurs with zirconium in the common accessory mineral, zircon. Hafnium has the unique ability to absorb neutrons, making it invaluable for use in control rods which regulate the fission process in the core of nuclear reactors of nuclear-fired power plants (U.S. Bureau of Mines, 1993b). In addition to its use in the nuclear industry, hafnium has application in the manufacture of superalloys.

Zircon occurs as an accessory mineral in virtually all igneous and metamorphic rocks in Colorado. The mineral is also frequently concentrated in placer deposits. Zircon is extremely abundant in the St. Peters Dome pegmatite deposits of El Paso County but has not been mined commercially. Zircon also occurs in the pegmatite deposits of Guy Hill and in the Bigger Mine, Jefferson County, and in magnetite deposits of the Beaver Brook area of Clear Creek County (Eckel, 1961). Hafnium may be of future commercial importance from the above mentioned Colorado deposits or might be recovered economically from placers.

Hafnium was produced by two U.S. companies in 1993, one in Oregon and one in Utah, as a byproduct of extracting zirconium metal from zircon sand in placer deposits. Availability of hafnium once again exceeded demand in 1993 due to the depressed state of the U.S. nuclear industry. Future demand would possibly consist of: superalloys, nuclear reactor control rods, and refractories/abrasives (U.S. Bureau of Mines, 1994).

Indium (In)

Indium is recovered from zinc ores, where it occurs in solid solution in the zinc sulfide mineral, sphalerite. The metal has also been reported in ores of copper, lead, and tin. Indium is used predominantly in thin film coatings as indium oxide or indium-tin oxide. Applications are in liquid crystal displays, infrared reflecting, transparent window coatings, windshield defrosters for airplanes, and defrosters for commercial freezer doors. Indium is also useful as an alloy metal. An increasing use of this metal is as a substitute for mercury in alkaline batteries, where it is used as a coating to inhibit corrosion of the zinc electrode (U.S. Bureau of Mines, 1993a).

Small amounts of indium were recovered at Asarco Inc.'s Denver smelter, but recovery was suspended in 1980 due to the low content of this metal in available feedstocks (Foster, 1991). It is highly probable that indium is a constituent of zinc ores available in many areas of Colorado. Sphalerite is very abundant in the state and has been mined for its zinc content in numerous mining districts. At present the total domestic demand for this metal is supplied from imported zinc ore feedstocks. Rising demand in the coatings and electronics industries since the 1980s has increased imports of indium dramatically (Foster, 1991). This fact indicates a need for research into the possibility of Colorado zinc ores as a future source of indium.

United States consumption of indium in 1993 consisted of: coatings (45%); solders and alloys (35%); electrical components and semiconductors (15%); and research and others (5%) (U.S. Bureau of Mines, 1994).

Iron (Fe)

Iron has been mined periodically in Colorado although no iron ore has been produced in recent decades. The most recent mining activity for primary iron ore has been at the Pitkin Iron Mine, high on the slopes of Taylor Peak in southern Pitkin County. This deposit is of contact metamorphic origin and consists of massive magnetite and pyrite replacing the Mississippian Leadville Limestone near the contact of a Middle Tertiary intrusive body. This open pit mine has been idle for a couple of decades.

Massive magnetite deposits, which are frequently enriched in titanium as inclusions of the iron-titanium-oxide, ilmenite, are fairly abundant and represent the most usual form of iron occurrence in Colorado. These deposits have been somewhat restrictive for use as primary ores of iron due to a generally low iron content and high levels of sulfur and silica which translate into increased production costs due to special metallurgical treatments (Vanderwilt, 1947). Most magnetite bodies which have been described and exploited are predominantly of contact metamorphic origin, although some appear to be the product of magmatic segregation. A partial list of these includes: veinlike segregations of titaniferous magnetite in granite and gneiss at Caribou Hill in Boulder County; magnetite and intergrown specular hematite which replace limestone at the Calumet Mine in the Turret district of Chaffee County; magnetite with disseminated specular hematite which replace limestone in the Grayback district of Costilla County; magnetite and ilmenite which occur as segregations in a large mass of gabbro at Iron Mountain in Fremont County; and large bodies of titaniferous magnetite which occur as segregations in mafic igneous rocks in the Cebolla district of Gunnison County (Eckel, 1961). These magnetite bodies have been exploited more for their precious metal content historically than as ores of iron, as magnetite has been shown to host gold and sometimes silver in many of these deposits.

Limonitic iron ore has been mined at only one location; the Orient Mine in Saguache County where limonite was produced from altered limestones on the west flank of the Sangre de Cristo Mountains. Gold was also recovered from this locality as a byproduct.

Competition between world iron ore producers remained intense in a declining market which currently favors large, high volume mines which benefit from the economy of scale. World production of iron ore has been in decline since the record year of 1989 when 926 million tons were produced. In that record year, 59 million tons of iron ore were produced domestically. In 1993, estimated United States production was 55.2 million tons from eight states, valued at $1.7 billion. United States consumption of primary iron ore in 1993 was as follows: blast furnaces (97.8%); direct reduction plants (0.8%); steel furnaces (0.1%); and manufacture of cement and other heavy-medium materials (1.3%) (U.S. Bureau of Mines, 1994).

Lead (Pb)

Lead is ubiquitous is almost every Colorado mining district as the sulfide mineral, galena, and has been continuously produced as a primary commodity throughout the state's 135-year mining history. This tradition continues to the present day. Production from the Black Cloud Mine in Lake

County, operated by Asarco Inc., amounted to an estimated 31,500,000 pounds of lead in 1992. The Black Cloud Mine also produced zinc, silver, and gold. Indeed, a large percentage of Colorado's total silver and some of its gold recovered to date have been directly related to the mining of galena ores. Silver commonly occurs as a solid solution or as microscopic intergrowths of argentite or other silver minerals in galena.

Native lead has been reported from Park, Summit, and Gunnison Counties, probably occurring as a secondary mineral in the oxidized zone, but none of the reports have been confirmed (Eckel, 1961).

Lead has also been produced from a number of other sulfide minerals but their combined totals equal only a small percentage of the total lead produced. In the Montezuma district of Park and Summit Counties, a lead-bismuth-sulfide, beegerite, has been identified in quartz-rich vein material. Both the lead-copper-bismuth-sulfide mineral, aikinite, and the lead-bismuth-sulfide mineral cosalite, have been mined in the La Plata Mountains of La Plata County, as ores of both lead and bismuth. These minerals occur in quartz veins where they are associated with pyrite, sphalerite, and native gold. Two sulfantimonides of lead, bournonite and boulangerite, have been identified in ores shipped from a handful of mining districts, most notably the Ruby-Elk district of Gunnison County and the Gilman district of Eagle County.

The lead telluride, altaite, occurs in many of the ores from the important telluride districts, such as the Boulder County telluride belt.

In the early days of placer mining near Leadville, Lake County, gold seekers were exasperated by a heavy blue mineral clogging their sluice riffles. This mineral would eventually be identified as cerussite, a carbonate of lead, leading to the discovery of the prolific lead-silver replacement deposits for which Leadville would become famous. The Leadville deposits are massive sulfide blankets which replace Paleozoic carbonate rocks in an area of multiple Tertiary intrusive events. As of 1961, an estimated $50 million worth of lead was recovered from cerussite in the rich oxidized zones of these mantos, most of which also contained argentite or cerargyrite (Eckel, 1961).

Cerussite, as well as the lead sulfate, angelsite, a transition mineral in the oxidation of galena to cerussite, has been an important source of lead in other mining districts. In the Monarch-Tomichi and Tincup districts of Chaffee and Gunnison Counties, cerussite is the predominant ore mineral in the oxidized zones of bedded replacement deposits and has also yielded free gold. Angelsite is present in the oxidized galena ores in many mining districts and certainly accounted for some of the lead values.

The total dollar value of lead produced to date in Colorado is subordinate only to that for molybdenum, gold, silver, and possibly zinc. The ambiguity between the total production of lead versus zinc arises because modern mine production figures combine data for these two metals, which are produced concurrently. The total dollar values of lead and zinc, reported in 1968 dollars for the period 1858–1962, are $334,151,000 and $373,026,000, respectively (Bergendahl, 1968).

United States domestic consumption of lead in 1993 consisted of: transportation (batteries, fuel tanks, solder, seals, and bearings) (70%); electrical, electronics, and communications (25%); with the remainder (5%) going into ballast and weights, ceramics and crystal glass, tubes and containers, type metal, foil, wire, kame, and specialized chemicals (U.S. Bureau of Mines, 1994).

Lithium (Li)

Lithium minerals have been produced commercially in Colorado but have probably not contributed significantly to the state's total dollar value from metallic elements. The three major source minerals of lithium, the lithium silicates, lepidolite and spodumene, and the lithium phosphate, amblygonite, have all been described in pegmatite deposits from a handful of Colorado mining districts. All of these minerals have been mined as ores of lithium; however, lepidolite seems to have been the most important economically.

The Quartz Creek (Ohio City) area of Gunnison County has a large reserve of lepidolite in the numerous pegmatites of the district and reportedly has produced several hundred tons (Eckel, 1961). Lepidolite is also described in pegmatites from Eight Mile Park, Fremont County. In the Crystal Mountain area of Larimer County "rotten" crystals of spodumene are described in a quartz-plagioclase pegmatite. Some of these crystals are reported to be up to 3 feet in length (Eckel, 1961). However, no production of lithium is reported from this district.

The United States is currently the world leader in both lithium production and lithium consumption. The United States maintained its status as a net exporter of lithium in 1993. Domestic consumption of lithium for 1993 consisted of: ceramics, glass, and primary aluminum production (60%); and lubricants and greases (40%) (U.S. Bureau of Mines, 1994).

Magnesium (Mg)

Magnesium metal is not recovered from mineral ores, but rather is concentrated through an electrolytic process from seawater and lake brines. Magnesium oxide was recovered from seawater by five U.S. compaies; from well brines by three U.S. companies; and from lake brines by two U.S. companies (U.S. Bureau of Mines, 1994). Magnesium, which is used as an alloy metal in the aluminum industry, is of no economic importance in Colorado.

Manganese (Mn)

Manganese minerals are fairly common in Colorado and have been mined in a few mining districts, predominantly for use as smelter flux. Ores mined in Colorado containing manganese have generally been of low grade and have, more often than not, been mined for their content of silver and other metals. High grade ores, those with a 35 percent or greater content of recoverable manganese, do occur and were mined periodically during World Wars I and II, and during the late 1950s. Past production records state that 31,000 short tons of high grade manganese ore were produced during these periods. On the other hand, low grade ores, those containing 10–25 percent manganese, have accounted for an estimated 1,000,000 tons. Most, if not all of this production has been from the Leadville District, Lake County (Crittenden, 1968).

Primary minerals of manganese in Colorado include: alabandite, a manganese sulfide; rhodochrosite, the manganese carbonate; and rhodonite, a manganese silicate. None of these minerals are mined as ores of manganese because they are: usually not very abundant in a deposit, are too refractory to be processed, or do not carry necessary concentrations of manganese. Rhodonite, and to a much lesser extent, alabandite, are common in the polymetallic veins of the Sunnyside Mine, San Juan County (Eckel, 1961). Beautiful crystals of rhodochrosite are being mined at present at the Home Sweet Home Mine in Park County, currently the world's best locality for large, blood-red, rhombohedral crystals of this highly prized manganese carbonate specimen mineral. A single crystal of rhodochrosite discovered at the Home Sweet Home Mine in 1992 measured 6 cm on a side.

Only alteration and oxidation products of the primary manganese minerals contain sufficient manganese to be mined as ores of this commodity. In the oxidized zone of manganese-bearing ore deposits, it is common for a number of manganese oxides to form. Simple oxides of manganese, notably pyrolusite and hausmannite, and manganese oxides in various states of hydration, collectively termed "wad", are known from Colorado mining districts. No record exists of any manganese production other than that previously stated from the Leadville district, Lake County.

United States net import reliance for manganese is 100 percent, as there are no high grade ores available domestically at this time. Import sources of manganese are South Africa, Gabon, Brazil, Australia, and Mexico. Major domestic end uses of manganese in 1993 were as follows: steel production (62%); construction (17%); and transportation (10%); and machinery (11%) (U.S. Bureau of Mines, 1994).

Mercury (Hg)

Mercury, or quicksilver, is known from a few Colorado mining districts but has been little more than an mineralogic curiosity. Mercury is the only metal which exists as a liquid at the temperatures and pressures of the earth's surface. The unique physical properties of this metal make it ideal for use as an indicator fluid in sensitive measuring and control instruments. Mercury also has important uses in electrical and electronic applications. However, recent demand is being offset by growing concern over the environmental and health risks associated with this known toxic metal.

Descriptions of quicksilver (native mercury) in Colorado have come exclusively from the state's telluride districts and are almost certainly attributable to the oxidation of mercury telluride minerals, although some may have been derived from mercury sulfides. The mercury telluride mineral, coloradoite, was originally described in 1877 from ores of the Boulder County telluride belt, where it was found to occur in quartz with native gold, native tellurium, sylvanite, and tellurite. Small blebs of quicksilver, some of which contain silver, are frequently observed on freshly broken surfaces of ore from the oxidized portions of these deposits. Coloradoite, associated with quicksilver, and amalgam have also been described in telluride ores of the La Plata Mountains, La Plata County, and from the rich telluride ores of the Cripple Creek district, Teller County (Eckel, 1961).

The mercury sulfide, cinnabar, is present in small quantities in some of the telluride ores from districts previously mentioned but nowhere does the mineral occur in great enough concentrations to be of economic interest. A deposit of cinnabar of possible commercial grade, associated with quartz and pyrite in breccia, is reported in Cochetopa Creek area of Saguache County (Vanderwilt, 1947).

In 1993 United States domestic consumption of mercury consisted of: electrical and electronic applications (25%); the manufacture of chlorine and caustic soda (30%); measuring and control instruments and in dental equipment (40%) (U.S. Bureau of Mines, 1994).

Molybdenum (Mo)

Molybdenum has accounted for the greatest dollar value of any metallic commodity mined to date in Colorado. Molybdenum is found in many areas of the state, occurring as the sulfide mineral, molybdenite. Molybdenite was recognized as an ore of molybdenum early on in the state's mining history but the commodity did not become of importance until World War I. At that time, 1917, the world-class Climax deposit was brought on line. Climax is one of the largest, if not the largest, known deposits of primary molybdenum ore in the world. At its height of production during World War II, Climax supplied 80 percent of the world's demand for this steel hardening alloy metal (Vanderwilt, 1947).

Production from another Colorado world-class molybdenum deposit, the Urad/Henderson, supplied close to half of world demand for molybdenum in 1992. A November 1993 merger of Cyprus Minerals Co. and Amax, Inc. effectively restructrued the ownership of both the Climax and Henderson mines under a new $5 billion company, Cyprus-Amax Minerals Co. The effect of this merger on the future of these mines is unknown at this time. In January 1993, Amax announced it was cutting production at the Henderson Mine by 40 percent in an attempt to deplete inventories to increase prices. The concerted effort by all primary molybdenum producers to effect the market by decreasing production was apparently successful as the price of the metal has risen from $1.90 per pound in January 1993 to $2.75 per pound by the year's end.

Other molybdenite occurrences in Colorado are numerous although most deposits are not of economic grade based solely on their molybdenum content. Molybdenum has been recovered from some of the precious and base metal deposits and from veins mined for beryllium, but values do not amount to a fraction of that mined at Climax and Urad/Henderson. Some of the occurrences of note are: massive molybdenite, some in flakes 1 inches long, associated with chalcopyrite, in the Magnolia district, Boulder County; quartz-beryl veins, which have produced large amounts of molybdenite and ferrimolybdite, in the Brown's Canyon area, Chaffee County; strongly developed veins of molybdenite and huebnerite in the Tincup district, Gunnison County; pipelike deposits of molybdenite and base metal sulfides in granite of the Lake George area, Park County; and molybdenite, chalcopyrite, sphalerite, and abundant magnetite, in a Precambrian massive sulfide deposit, Prairie Divide area, Larimer County (Eckel, 1961).

The Climax Mine is located east of Fremont Pass in Lake and Summit Counties. Since the mine's initial development in 1917, it has been operated almost continuously and has produced close to 1 billion pounds of molybdenum. In recent years the mine has been on standby status and production has shifted to the Urad/Henderson Mine in Clear Creek County.

The Climax deposit is a large, mineralized stockwork associated with the multiphase Middle Tertiary Climax Stock. The stock was emplaced in four seperate events, or lobes, each with its own associated hydrothermal phase. Three of these events produced stockwork-type molybdenum ore bodies, which cap and flank their respective source lobes, in fractured and altered country rocks. A fourth intrusive phase was barren of mineralization. The three productive Climax ore bodies are of a similiar nature, consisting of molybdenite mineralization which occurs in zones of intense silicification located on and across the upper contacts of each lobe of the stock. Molybdenite mineralization is flanked by zones of pyrite-tungsten mineralization. The various ore bodies overlap to a degree but are mostly distinguishable from one another. The Climax Stock was intruded into Precambrian metasedimentary rocks, which have been intruded by dikes and sills of Climax porphyry, on the footwall side of the northeast-trending, west-dipping Mosquito Fault. Molybdenum ore at Climax is hosted both in altered Precambrian metasediments and in rocks of the Climax Stock itself. Glaciation and erosion had mostly removed the uppermost ore body and partially exposed a second ore body prior to mining at Climax (Wallace et al., 1968).

The Urad/Henderson Mine is located in the vicinity of Red Mountain in Clear Creek County, 9 miles west of Empire. In recent years this porphyry molybdenum deposit has accounted for most of Colorado's production of molybdenum. Development of this molybdenum deposit began during World War I at the Urad Mine. The Urad Mine produced molybdenite ore, some of it quite high-grade, from shear zones localized in and around the Red Mountain granite porphyry stock. Molybdenite was also mined from numerous veinlets and in disseminations in the both the granite porphyry stock itself, and in a zone of fractured and altered granite around the southern margin of the stock (King, 1968). Current mining operations at the Henderson Mine are exploiting the porphyry molybdenum core of the deposit some 2000 feet below the Urad zone.

The United States continued to be a net exporter of molybdenum in 1993. The Henderson Mine in Colorado accounted for the only domestic production of primary molybdenum ore, with 10 other mines in

Arizona, California, Montana, New Mexico, and Utah, recovering molybdenum in 1993 as a byproduct of the mining of other metals. The majority (75%) of domestic molybdenum consumption for 1993 was in the production of iron and steel. Major end-uses of molybdenum were machinery (35%); electrical (15%); transportation (15%); chemicals (10%); oil and gas industry (10%); and other (15%) (U.S. Bureau of Mines, 1994).

Nickel (Ni)

Nickel is a strategic metal and is valued for the strength, heat-resistance, and the anti-corrosive properties it imparts to other metals when alloyed. This element is not currently produced in Colorado, although some deposits in the state are known to be of ore grade. Both of the known Colorado deposits have supplied nickel ores in the past but have not accounted for significant quantities on a world market scale.

Nickel and iron were some of the first metals utilized by mankind. Meteoric iron contains up to 26 percent nickel and was used as early as 4000 B.C. when early peoples discovered they could fashion the strange heavy rocks into tools and weapons. Nickel has been recognized in Chinese coins dating from 800 B.C. and from Greek coins dating from 300 B.C. (U.S. Bureau of Mines, 1993b).

In modern times, nickel is usually recovered from the processing of nickel sulfide ores and from laterite deposits (Bleiwas, 1991). Nickel deposits in Colorado are of the sulfide type, consisting of the nickel sulfide minerals, millerite and polydymite, and the nickel-iron sulfides, bravoite and pentlandite. Although these deposits have produced a few tons of nickel ore, they are insufficient in grade and tonnage to compete with large, currently producing mines in Sudbury, Canada and New Caledonia. In the Copper King Mine, Gold Hill district, Boulder County, polydymite is the primary nickel ore mineral and occurs with bravoite, pentlandite, and millerite, in coarse-grained zones in amphibolite. At Garden Park, Fremont County, millerite occurs in quartz geodes with calcite and barite (Eckel, 1961).

Other Colorado nickel occurrences are little more than mineralogic curiosities. The nickel arsenide, niccolite, is found in Boulder, and Fremont Counties. Skutterudite, an arsenide of nickel and cobalt, is described from the Elk Mountains of Gunnison County. The nickel telluride mineral, melonite, has been found in Boulder County telluride ores, and at the Cripple Creek deposits of Teller County, associated with native gold (Eckel, 1961).

The Glenbrook Nickel Co., a subsidiary of Cominco American Resources, was the sole United States producer of nickel for 1992, receiving feedstock both from their Nickel Mountain Mine, and imported ores from New Caledonia, at their smelter located in Riddle, Oregon. (U.S. Bureau of Mines, 1993c). A large portion of world supply of this metal comes from enormous deposits at Sudbury, Ontario, Canada, which have been continuously mined since 1890. In 1993, nickel was used for: stainless and alloy steel production (42%); nonferrous alloys and superalloys (36%); electroplating (18%); and other uses (4%) (U.S. Bureau of Mines, 1994).

Niobium (Nb) and Tantalum (Ta)

Niobium and tantalum are combined because they have consistently been produced together in Colorado, and are not seperated in state production records. These elements substitute isomorphously into some of the same minerals and usually both occur in varying quantities in ores derived from these minerals. Tantalum has a much lower crustal abundance than does niobium.

Niobium, sometimes refered to as columbium, is a refractory metal which is characterized by a high melting point, resistance to corrosion, and ease of fabrication. These attributes render the metal useful as an alloying agent in steel and superalloys

(U.S. Bureau of Mines, 1993b). The element was discovered in 1801 and was originally named columbium. Niobium was the name officially adopted for the element by the Union of Pure and Applied Chemistry in 1950, and is the name used by chemists and physicists. The name columbium seems to be the more popular of industry, especially in the United States.

Tantalum is also characterized by a high melting point, ease of fabrication, and strong corrosion resistance. The major end-use of tantalum is in the electronics industry where it is used in the manufacturing of tantalum resistors.

The minerals from which columbium and tantalum were first isolated is the columbite-tantalite isomorphous series. They are iron-manganese-oxide minerals which form a solid solution series with the niobium end member, columbite, grading through the tantalum rich end member, tantalite. The predominant source minerals for niobium and tantalum are pyrochlore-microlite, a series of calcium-sodium-oxides, with the niobium end member, pyrochlore, grading through the tantalum end member, microlite. These minerals commonly occurs as constituents of carbonatites, and in pegmatites. The majority of the currently identified world supply of niobium and tantalum is outside of the United States, contained in deposits of pyrochlore-microlite (U.S. Bureau of Mines, 1993a).

Colorado had a recorded production of 20,000 pounds of niobium-tantalum concentrates as of 1968. This production has been predominantly from columbite-tantalite ores recovered from zoned pegmatite deposits, although microlite, euxenite, fergusonite, and samarskite have all been marketed. Production since this time has been minimal to non-existent. The productive pegmatite deposits from which these minerals have been commercially extracted are in a north-south trending belt, from Larimer County in the north, to Fremont County in the south. All of the pegmatites are in exposed Precambrian rocks of the Front Range. A few pegmatites were mined for niobium and tantalum in the Sawatch Range, Chaffee County (Parker, 1968).

A large resource of niobium exists in alkalic rock complexes in Colorado. Most notable is the Powderhorn complex, Gunnison County, which has an identified resource of niobium contained in pyrochlore. The ore minerals are dispersed throughout the central carbonatite core of the complex, and also into pyroxenites and fenitized granites peripheral to the core (Olson and Wallace, 1956). Reserves of niobium at Powderhorn are estimated to be "considerably more than 100,000 tons of Nb_2O_5, in rock averaging at least 0.25 percent Nb_2O_5" (Grogan, 1960 in Parker, 1968). Pyrochlore and other niobium minerals, as well as minerals of the rare earths and titanium, occur in the alkalic rock complexes of the Wet Mountains, Fremont and Custer County, within carbonatite dikes associated with complexes of gabbro-pyroxenite, syenites, and nepheline-bearing mafic rocks.

United States consumption of columbium (niobium) in 1993 consisted of: high-strength, low-weight alloys (40%); carbon steels (32%); superalloys (13%); stainless and heat resisting steels (13%); and other (2%) U.S. Bureau of Mines, 1994).

Platinum Group Elements (PGE)

The platinum group metals are platinum, palladium, rhodium, ruthenium, iridium, and osmium. These metals are usually recovered from nickel-copper sulfide ores associated with ultramafic intrusive rocks. Platinum, palladium, and a little iridium are known to occur in Colorado, but they have never been produced as a primary commodity. The platinum group metals were mined at one operation in Montana in 1993 (U.S. Bureau of Mines, 1994).

Platinum, palladium, gold, and silver are associated with finely disseminated chalcopyrite in the Laramide-age Allard alkalic stock, La Plata County. The Allard Stock is a multiphase, epizonal syenitic intrusive with a complex history of emplacement, alteration, and mineralization. Trace-element analyses reveal enrichment of volatiles (CO_2,F,S), and elevated concentrations of copper, arsenic, tellurium, bismuth, and the precious metal mentioned above (Werle et al., 1984).

Platinum has been described in black sand from placer deposits near Buena Vista, Chaffee County, and from Ouray County. Occasionally, small amounts of platinum and iridium have been recognized in assays from gold and silver ores mined in: the Georgetown district, Clear Creek County; the White Cross district, Hinsdale County; the Granite district, Lake County; the Aspen district, Pitkin County; in the Mosquito Gulch area, Park County; at the Liberty mine, Saguache County; and in the Telluride district, San Miguel County (Eckel, 1961).

United States consumption of the platinum group metals in 1992 consisted of the following end-use catagories: automotive (38%); electrical and electronic (29%); dental and medical (9%); chemical (4%); petroleum refining (5%); and other (15%) (U.S. Bureau of Mines, 1993a).

Potassium (K)

Potassium, like calcium and sodium, is a constituent of most common rock-forming minerals, especially the orthoclase feldspars and mica minerals. Potassium minerals in amounts sufficient enough to merit economic attention are found in sedimentary evaporite sequences.

Sylvite occurs along with halite, anhydrite, dolomite and fine-grained clastic rocks in several evaporite sequences in the Pennsylvanian Paradox Formation of the Paradox basin of southwestern Colorado and neighboring Utah. There is no commercial development of sylvite in Colorado; however, it and other salts have been mined near Moab, Utah.

Carnallite is reported from the abandoned Nineteenth Century salt works near the present day site of Antero Reservoir, Park County (Eckel, 1961).

Alunite occurrences in Colorado were briefly investigated as a source of potash during World War I when German supplies were cut. Alunite is a common alteration product of hydrothermal systems, especially in volcanic rocks. Significant alunite occurrences are found in the Rosita Hills, Custer County; Calico Peak near Rico, Dolores County; Summitville, Rio Grande County; and at several localities in the Lake City district, Hinsdale County (Argall, 1949).

Several varieties of feldspar which contain potassium are found throughout the State. Adularia, the nearly pure potassium-bearing variety, is a common gangue mineral and alteration product in many mining districts. Adularia as well as other orthoclase feldspars, such as microcline, are typical constituents of pegmatite bodies.

Rare-Earth Elements (REE)

The rare-earth metals are 15 elements grouped together on the periodic table by increasing atomic number. These elements, sometimes refered to as the "lanthanides", consist of: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). The first seven elements of this series, lanthanum through europium, are known as the "cerium group" of rare-earth metals because cerium is the most common. The cerium group is sometimes referred to as the "light rare earths". The remaining eight elements, gadolinium through lutetium, are referred to as the "heavy rare earths". The properties of the "light" and "heavy" groups of rare earths are sufficiently distinct that they are frequently segregated in rare-earth minerals, which tend to be of one group or another, although all 15 elements can occur together (Adams, 1968).

The rare-earth metals occur in many minerals as trace elements but are only known to be concentrated in recoverable quantities in a few species. Probably the most common source mineral is the rare-earth phosphate, monazite, which can contain 55 to 60 percent rare-earth oxide and up to 10 percent thorium oxide (Kelly, 1962). The rare-earth fluorcarbonate, bastnaesite, is also an important ore mineral of the rare earths, including yttrium. Bastnaesite is the source mineral currently mined at Mountain Pass, California. Both monazite and bastnaesite typically contain the "light rare earths"; whereas, the "heavy rare earths" are contained in the yttrium phosphate mineral, xenotime, and the oxide, euxenite. Other minerals from which rare-earth elements have been recovered include: a cerium group-bearing fluorite mineral, fluocerite; a rare-earth carbonate-fluoride, synchisite; a hydrated rare-earth carbonate, lanthanite; an oxide of yttrium and rare earths, samarskite; and the rare-earth silicate, allanite.

Minerals of the rare-earth metals are known from numerous locations in Colorado where they occur in varied geologic environments. All of the above mentioned minerals are known to occur in various combinations in the state and have been described in pegmatites, carbonatites, placers, vein deposits, and in igneous and metamorphic rocks. Only one of these deposit types is responsible for commercial production of rare earths.

The small amounts of rare-earth metals extracted to date in Colorado have been as a byproduct of the mining of zoned pegmatites. These deposits, the most productive of which have been in the South Platte district, Jefferson County, have historically been worked for feldspar, quartz, beryl or mica. Any rare earths recovered from the mining of these pegmatites has coincided with the discovery of large, singular crystals of rare-earth minerals of ample size to encourage their sale as high-grade, rare-earth ores. In the South Platte district, allanite, monazite, bastnaesite, xenotime, and synchisite occur in zoned pegmatites, sometimes in large crystals. Allanite and monazite have been the most productive in terms of rare-earth metals recovered in the Jefferson County deposits. Other notable pegmatite deposits with known concentrations of rare-earth minerals occur: at Jamestown, Boulder County; in the Burroughs Mine near Bergen Park, Jefferson County; at the Teller prospect of Lake George, Park County; in the Trout Creek area of Chaffee County; in the Guffey area, Park County; at Saint Peter's Dome, El Paso County; and in the beryllium-rich pegmatites of the Quartz Creek district, Gunnison County (Adams, 1968).

In the Powderhorn alkalic complex of Gunnison County, bastnaesite, synchisite, xenotime, and abundant rare-earth bearing apatite are found in veins associated with thorium minerals. The veins contain quartz, feldspar, carbonate minerals, barite, thorite and thorogummite, and are impregnated with iron-oxides. The district has over 200 of these veins which are typically steeply-dipping, and range in widths from a fraction of an inch to 10 feet (Hedlund and Olson, 1961). In the Wet Mountains of Custer County, rare-earth bearing apatite, and bastnaesite, occur with thorium minerals in similiar veins associated with three alkalic rock complexes found in the area. Neither of these deposits have been exploited for rare-earth minerals to date.

Monazite represents a large percentage of world reserves of rare earths and is recovered predominantly from recent and ancient placer deposits formed by the concentration of heavy fraction minerals from the weathering of igneous and metamorphic rocks. In Montezuma County, Colorado, monazite-bearing fossil placer deposits, occurring in sandstones of Late Cretaceous age, contain monazite and oxides of titanium and zirconium (Dow and Batty, 1961). Fossil placer deposits which contain monazite and native gold are known from the Timberlake area, Moffat County, but have never produced rare-earth elements.

Demand for rare earths in 1993 was somewhat stronger than in 1992 as reflected in a general strengthening of most end-use markets. Demand is increasingly shifting toward high-purity compounds, metals, and special mixtures. A great deal of research and development into new uses for the rare earths should improve markets as new applications are adopted (U.S. Bureau of Mines, 1994). The next growth sector for the rare-earth metals is in lanthanum-nickel and mischmetal-nickel alloys used in rechargeable batteries (U.S. Bureau of Mines, 1993a).

Rhenium (Re)

Rhenium resembles manganese in general chemical behavior and was first isolated from samples of pyrolusite (MnO_2). Rhenium is not, however, recovered from ores of manganese, but occurs as a constituent in molybdenum concentrates derived from porphyry copper deposits. Rhenium of recoverable grade occurs only with molybdenite associated with porphyry copper deposits, and is, therefore, a tertiary product of copper and molybdenum. During 1992, Cyprus Minerals Co. recovered rhenium from ores mined by seven domestic porphyry copper operations in the southwestern part of the country (Foster, 1991).

There is no known resource of rhenium in Colorado at this time. There has been no recorded historic production of the metal despite the fact that large porphyry molybdenum deposits at Climax and Urad/Henderson have produced well over 1 billion pounds of molybdenum. This is due to the fact that rhenium is not a recoverable trace metal in these molybdenum dominated deposits.

Rhenium is used as a petroleum reforming catalyst for the production of high-octane hydrocarbons, and in high-temperature superalloys used in jet engine components. In the United States in 1993, rhenium alloys were also used in thermocouples, temperature controls, heating elements, ionization gauges, mass spectrographs, electron tubes and targets, electrical contacts, metallic coatings, vacuum tubes, crucibles, electromagnets, and semiconductors (U.S. Bureau of Mines, 1994).

Rubidium (Rb)

Rubidium does not form minerals in which it is the dominant metallic constituent but it can substitute for potassium in late-stage pegmatite minerals. The majority of the world supply of this metal is contained in lepidolite ores, none of which are mined in the United States. Lepidolite, a potassium-lithium mica, may contain up to 1.35 percent rubidium. A cesium silicate, pollucite, can contain up to 3.15 percent rubidium (U.S. Bureau of Mines, 1993b).

Lepidolite occurs in a number of Colorado pegmatite districts and has been mined as a commercial mineral. There are no data on any recovery of rubidium from the processing of these small lots of lithium ore. Several hundred tons of lepidolite ore were mined at the Brown Derby Mine and other claims in the Quartz Creek district, Gunnison County (Eckel, 1961). Reserves of lepidolite ore in the district are reportedly large and may represent a future supply of rubidium. These ores have not been studied for trace metal content.

Small amounts of rubidium-bearing minerals were produced in the United States prior to 1960. In recent years imported lepidolite ores have originated mostly in Canada. The market for rubidium is small and consequently the metal is not traded and there is no posted price. The metal is used in the form of chemical compounds for research and development. Rubidium is also used in electronic and medical applications (U.S. Bureau of Mines, 1994).

Selenium (Se)

Domestic production of selenium in 1993 amounted to $2.8 million, all of which was recovered from anode slimes generated in the electrolytic refining of copper (U.S. Bureau of Mines, 1994). In addition to reserves of selenium in identified copper deposits, it is estimated that a larger reserve exists in copper and other metal deposits not yet developed. Coal contains an average of 1.5 parts per million selenium but it is unlikely to be a future source of this metal (U.S. Bureau of Mines, 1993b).

Colorado has not been a large producer of primary copper ores from which selenium is normally recovered. It is possible that some of the copper minerals which occur in many of the State's mining districts could be identified as a future source of selenium but the prospect seems unlikely due to the accessory nature of copper in most ore deposits. Selenium may be a trace metal in sandstone hosted copper-uranium deposits. The metal has not been produced commercially in Colorado to date.

In 1993, domestic consumption of selenium was as follows: electronics (35%); chemical and pigments (20%); glass manufacturing (30%); and other, including agriculture and metallugry (15%). In the electronics industry, refined selenium was used as a photoreceptor on plain paper copier drums (U.S. Bureau of Mines, 1994).

Silver (Ag)

Of the metals produced in Colorado to date, the total value of silver is exceeded in dollar amount only by that of gold and molybdenum. The diversity of minerals from which this element has been produced is second to none with some 22 representative species identified as silver contributors.

Although early mining efforts were concentrated on the search for gold, silver came to prominence in the latter portion of the 19th Century when it was used as the national monetary standard, giving rise to the slogan: "Silver is King".

A large amount of silver has been produced from extremely rich, massive sulfide replacement deposits in Paleozoic limestones and dolomites peripheral to the Sawatch Uplift of central Colorado. The most prolific of these deposits have been those in the Leadville district, Lake County. The silver in these deposits occurs either as elemental silver in solid solution with lead sulfide molecules in galena, or as fine inclusions of the silver sulfide, argentite, in galena and other base metal sulfides.

Important contributing silver production has also been realized from numerous Colorado mining districts in the form of veins, stockworks, and replacement deposits rich in a wide variety of silver minerals including: silver sulfides, silver antimonides, silver arsenides, silver chlorides, and gold-silver tellurides. In addition, a large quantity of silver has been recovered from rich vein and replacement ores of the gray copper minerals, which form a solid solution between the antimony end member, tetrahedrite, and the arsenic end member, tennantite. These minerals can host large amounts of silver, either in their crystal lattice or as small inclusions of primary silver minerals.

Small amounts of silver have been produced from stratabound Precambrian massive-sulfide ores, some of which resemble exhalative type deposits (Sheridan et al., 1990). Minor amounts of silver can occur in pegmatites, but the metal has never been recovered in quantity from this source.

Domestic usage of silver in 1993 was as follows: manufacture of photographic products (50%); electrical and electronic products (20%); electroplating, sterlingware and jewelry (10%); and other uses (20%) (U.S. Bureau of Mines, 1994).

Sodium (Na)

Halite, the most common sodium mineral, was produced for a brief period from wells in the South Park area, Park County near the present site of Antero Reservoir. These salt works were established during the 1860s and were abandoned by the late 1870s (Eckel, 1961). Significant salt deposits have been encountered during oil well drilling programs in Pennsylvanian evaporite deposits in the Paradox basin of southwestern Colorado and in Permian lacustrine sediments in northeastern Colorado.

Nahcolite, dawsonite, and halite are associated with lacustrine sediments and oil shale beds in the Tertiary Green River Formation of the Piceance Creek Basin, Rio Blanco County, Colorado. These minerals occur as stratiform layers and attain their highest concentration in the basin center. The estimated resource is staggering; 29 billion tons of nahcolite and 19 billion tons of dawsonite (Beard et al., 1974). Approximately 20,000 tons of nahcolite were produced from a solution mining facility in the Piceance Creek Basin in 1992.

Natron, trona, thenardite, and mirabilite are found as efflorescences around ephemeral ponds and lakes in Jefferson County and in the San Luis Valley. Natrolite, a sodium zeolite, occurs with other zeolite minerals in volcanic rocks at Iron Hill, Gunnison County; Table Mountain, Jefferson County; and in South Park, Park County (Eckel, 1961).

Salt production during 1993 in the U.S. was valued at $854 million. The chemical industry used 44 percent of produced salt; 21 percent was used for highway deicing; 11 percent went to food and agricultural uses; and 16 percent to other assorted uses U.S. Bureau of Mines, 1994.

Strontium (Sr)

The principle ore mineral of strontium is celestite. This sulfate mineral occurs in geodes and other concretions in sedimentary rocks, and less frequently, as a primary gangue mineral in vein-type metal deposits. The strontium carbonate, strontianite, has not been important as an ore of the metal. Strontianite is found associated with celestite in many localities but is usually the more rare of the two minerals.

Celestite has not been mined commercially in Colorado although it is known from a few mining districts. In the Cripple Creek district, Teller County, thin prisms of celestite were formed in veins during a precious metal-rich, telluride stage of mineralization. In the Cresson Mine, large quantities of calaverite, a gold telluride, were contained in porous white celestite. Celestite occurs sparsely in veins in the Jamestown district, Boulder County (Eckel, 1961).

Beautiful crystals of celestite are found in lenticular masses in Triassic red sandstones in the Garden of the Gods area, El Paso County. Celestite occurs as perfectly formed blue and transparent crystals, frequently coated with small spheres of strontianite, or as a blue fibrous mass, in geodes. Blue and pink celestite, yellow calcite, and clear to amber barite, line quartz geodes found in the Morrison Formation, Garden Park area, Fremont County. Beautiful blue crystals of celestite are reported from Apishapa Creek in Otero County (Eckel, 1961).

Worldwide strontium demand increases were offset by increases in world production in 1992, causing a further decline in markets for this metal. Strontium has not been produced in the United States since 1959. Last year, 97 percent of imported strontium and strontium compounds came from Mexico, with Germany and Spain accounting for the remainder (U.S. Bureau of Mines, 1993a). Imports for consumption for 1993 were exclusively from Mexico. During 1993, strontium was used in the faceplate glass of color television picture tubes (67%); pyrotechnics and signals (11%); ferrite ceramic magnets (12%); and other uses (10%) (U.S. Bureau of Mines, 1994).

Thallium (Tl)

Thallium is recovered as a byproduct of the smelting of copper, lead, and zinc ores. The metal occurs as a trace element in many minerals, but is the most concentrated in zinc sulfide ores, in which it has an estimated average abundance of 2.2 parts per million. Thallium is a soft, bluish-white, malleable heavy metal with importance in current research in superconductors and alloys. Thallium metal and its compounds are highly toxic to humans. In 1965, Federal regulations banned the use of thallium sulfate as a rodenticide. Prior to this time the metal and its compounds were in wide use. Strict governmental controls are now placed on the metal and its compounds because of multiple absorption into the human body through skin contact, ingestion, or inhalation (U.S. Bureau of Mines, 1993b).

Base metal ores mined or processed in the United States in 1992 contained thallium, but none was recovered (U.S. Bureau of Mines, 1993a). Recovery of thallium metal and its compounds ceased domestically in 1981 when production was discontinued at the Asarco smelter, Denver, Colorado, due to shrinking markets and increased environmental concerns (Foster, 1991). The source material for this modern thallium production was most likely out-of-state precious/base metal concentrates, although some received concentrates may have originated in Colorado. Recovery of thallium from Colorado lead-zinc ores is reported from the early 1900s by George (1913). Sphalerite is ubiquitous in the State's mining districts and may prove a future source of thallium and many other trace metals.

In the case of thallium, environmental concerns will continue to dominate the domestic market for this metal by causing a strictly controled, 100 percent net import reliance to remain in effect. Research and development into thallium-based superconductors accounted for 50 percent of domestic consumption, with electronics, alloys, glass manufacturing, and pharmaceuticals making up the balance (U.S. Bureau of Mines, 1994).

Thorium (Th)

The principle ore mineral of thorium is monazite, a rare-earth thorium phosphate. This naturally radioactive mineral is mined both for its rare-earth and thorium content. Monazite occurs in several of Colorado's pegmatite districts, and is also known as a vein mineral. Monazite also occurs as a minor constituent of a porphyry molybdenum deposit. Monazite has been produced from all of these deposit types.

Thorium, like uranium, is the parent of a series of radioactive decay products which terminate in a stable isotope of lead. Thorium minerals are much more stable during weathering than are uranium minerals, and as a result tend not to be concentrated in meteoric water dominated, secondary low-temperature vein and roll-front type deposits as do the uranium minerals.

In 1950, 26 tons of monazite were produced as a byproduct of molybdenum mining at Climax, Lake County. In this same period, small amounts of thorium were recovered from multiple oxide ore mined from pegmatite deposits around the State. The thorium-bearing multiple oxide minerals which have mined commercially from Colorado pegmatites are euxenite, samarskite, and fergusonite. These minerals have been mined predominantly for their rare-earth content with thorium recovered as a byproduct. Recovery of thorium is also reported from pegmatite mines for the years 1956 and 1957. Thorium minerals have been described from numerous pegmatite areas in Colorado. Districts with production from pegmatite deposits include: Quartz Creek, Gunnison County; Trout Creek Pass, Chaffee County; Centennial Cone area, and the Burrough's Mine, both in Jefferson County; and Prairie Divide area, Larimer County (Eckel, 1961).

The thorium silicate minerals, thorite and thorogummite, occur in vein deposits associated with quartz, barite, common sulfides, iron oxides, feldspar, and rare-earth minerals near the Iron Hill alkalic complex, Powderhorn district, Gunnison County. These thorium silicate minerals also occur in Precambrian shear zones in the Wet Mountains of Custer and Fremont Counties, associated with rare-earth minerals, quartz, barite, limonite, hematite, fluorite, siderite, galena, chalcopyrite, and bornite. The Wet Mountains mineralization is related to three Cambrian alkalic rock complexes intruded into Precambrian metasedimentary and metavolcanic rocks. Total production, if any, from these districts has been minimal (Eckel,1961).

Environmental concerns over thorium's natural radioactivity have increased costs associated with handling, storing, monitoring, shipping, and proper disposal of the metal. This has effected the market and has caused consumers to search for less restrictive alternatives to thorium. In 1993, 19 domestic companies processed or fabricated various forms of thorium for non-energy use as follows: ceramics, carbon arc lamps, magnesium-thorium alloys, refractories, and welding electrodes. The value of domestically consumed thorium metal and compounds was estimated at $500,000 (U.S. Bureau of Mines, 1994).

Tin (Sn)

Tin is important as a plating metal, in the manufacture of solders, and in bronze and other alloys. The metal has never been produced as a primary commodity in Colorado but has been recovered as a byproduct. The United States has been the world's leading consumer of tin for most of the Twentieth Century, even though there has never been a substantial domestic tin mining industry. However, in 1993, small amounts of tin concentrates were produced from a placer mining operation in Alaska (U.S. Bureau of Mines, 1994). Recycling of tin is having an ever-increasing effect on markets worldwide.

The only recognized ore mineral of tin is the tin oxide, cassiterite. Due to the lack of economic grade deposits in the United States, and the accompanying heavy reliance on foreign imports, much diligence has gone into the search for domestic tin deposits in Colorado and other states. Despite this intensive search, in Colorado only the Climax molybdenum-porphyry deposit, Lake County, has ever shown any potential as a source of tin, albeit a minor one. Cassiterite occurs as small crystals in vugs, in pockets of sericite, and in veinlets of quartz-pyrite-sericite in the Climax deposit (Wallace et al., 1968). More commonly, tin is present in only trace amounts but because of the large tonnages of ore mined at Climax for molybdenum, tin has been recovered in salable amounts as a byproduct (Eckel, 1961). A few minor occurrences of cassiterite in pegmatites, and in veins of beryl, have been described but are not important as sources of this metal.

Leading world producers of tin are Great Britain, Brazil, China, Indonesia, Malaysia, and Thailand (U.S. Burearu of Mines, 1993a). Domestic consumption of tin in 1993 consisted of: cans and containers (32%); electrical (22%); construction (10%); transportation (11%); and other uses (25%) (U.S. Bureau of Mines, 1994).

Titanium (Ti)

Titanium is currently produced as sponge-metal for use in high strength alloys, or as titanium dioxide (TiO_2), which is used as a pigment. In 1993, three companies in Nevada, Ohio, and Oregon, produced titanium sponge-metal and seven companies produced titanium metal ingot (U.S. Bureau of Mines, 1994). World titanium resources are contained in the mineral rutile, an oxide of titanium, and in the iron-titanium-oxide mineral, ilmenite. A resource of titanium contained in the calcium-titanium-oxide mineral, perovskite, is located in the Powderhorn district in Gunnison County.

In Colorado, rutile is known as an accessory minerals in igneous and metamorphic rocks, and as a concentration in "heavy fraction" minerals in stream gravels derived from the erosion of terrains of these rocks. In addition to these occurrences, rutile is described as a minor vein and wallrock mineral, and in a few pegmatites from some of the State's mining districts. Rutile is not present in concentrations to be valuable as a ore of titanium. In the Saint Peter's Dome area of El Paso County, small prisms of rutile are associated with reddish-brown microcline, arfvedsonite, and zircon in quartz. In the same general area, rutile, which contains tin, occurs as small black crystals in quartz which fills cavities in altered pink orthoclase. Rutile occurs in sericitic fault gouge, in vein quartz, and in silica-dominated replacement deposits in the Bonanza district, Saguache County. In the Cripple Creek district, Teller County, minute crystals of rutile occur as an alteration product of ilmenite in the wallrock of veins (Eckel, 1961).

Bodies of titaniferous magnetite ore, with ilmenite and green spinel occurring in veinlets and stringers of magnetite in mafic intrusive rocks, crop out on the slopes of Caribou Hill, Boulder County. These ores range from 3 to 5 percent TiO_2. Iron Mountain in Fremont County consists of gabbro containing lenses of titaniferous magnetite up to 50 feet wide. This ore contains 12.95 percent TiO_2 as ilmenite. In the Cebolla district, Gunnison County, a body of titaniferous magnetite occurs near the alkalic complex at Iron Hill, south of Powderhorn. Ilmenite and magnetite occur with bunches of dark-brown mica as segregations in mafic igneous rocks. Magnetite-ilmenite ores also occur at Iron Hill in a contact-metamorphic zone in limestone (Eckel, 1961).

Perovskite occurs as a primary mineral in uncompahgrite rock at Iron Hill, Powderhorn district, Gunnison County, occurring with magnetite, melilite, and garnet (Eckel, 1961).

The majority of titanium metal consumed in 1993 was used in jet engines, airframes, and space and missile applications (75%); the remainder being used in the chemical-processing industry, power generation, marine and ordnance, medical, and other non-aerospace applications (25%). Titanium dioxide (TiO_2) pigment was used in paint, varnishes, and lacquers (45%); paper (26%); plastics (18%); rubber (2%); and other (9%) (U.S. Bureau of Mines, 1994).

Tungsten (W)

Tungsten has been an important commodity in Colorado in the past but the industry has been dormant in recent decades. In 1993, one mine in California accounted for the total domestic production of this metal. The melting point of tungsten (3,410 degrees C) is higher than that of any other metal. This property, coupled with its high-shock-resistance and favorable luminescent quality, render this metal indispensible for use as a filament in lighting fixtures. Tungsten also has gained wide use as an important alloying agent in high-speed cutting tools (U.S. Bureau of Mines, 1994).

Colorado has posted impressive tungsten production figures from three major districts. The famous Boulder County Tungsten Belt was an important producer of tungsten from ores of the wolframite series of minerals, which occur in chalcedonic quartz veins emplaced in Precambrian granite and metamorphic host-rocks. The wolframite series of minerals are a solid solution of iron and manganese tungsten-oxides, with end member, ferberite, the iron-tungsten-oxide, grading through the manganese-tungsten-oxide end member, huebnerite. Tungsten minerals in the Boulder County ores tend to exist as the iron-rich end member, ferberite, forming the matrix in brecciated veins of chalcedony or country rock. Some of these ores are quite rich with tungsten values running as high as 20 percent WO_3 (Hobbs, 1968). Production from this district peaked during World War II and steadily declined through the 1960s.

At the Climax Mine, Lake County, huebnerite is found as tiny grains scattered irregularly in quartz-pyrite-sericite veinlets, in zones peripheral to molybdenite mineralization (Wallace et al., 1968). Climax has contributed a significant amount of tungsten as a byproduct of the mining of molybdenite ores.

The calcium-molybdenum-tungsten-oxide mineral, powellite, is associated with garnet and epidote in a stratabound deposit in schist, 2 miles south of Blackhawk, Gilpin County, and accounted for minor tungsten values from one shipment of ore reported in 1943 (Eckel, 1961).

Scheelite, the calcium-tungsten-oxide, is described from numerous mining districts, occurring in calc-silicate gneiss, amphibolite, and impure marbles. These deposits have not been of importance in total production of tungsten in Colorado.

United States net import reliance for tungsten in 1993 was 84 percent. Major domestic end-uses of tungsten in 1993 were: metalworking, mining, and construction machinery (71%); lamps and lighting (9%); electrical and electronic machinery and transportation (10%); chemical (5%); and other uses (5%) (U.S. Bureau of Mines, 1994).

Yttrium (Y)

Yttrium was recovered from ores mined by three companies domestically in 1993. The rare-earth metal, yttrium, is obtained from ores of the phosphate mineral, monazite, and to a lesser extent, from the rare-earth fluorcarbonate, bastnaesite. Monazite was recovered as a byproduct of processing of heavy-mineral sands for titanium and zirconium minerals. A company in New Jersey recovered yttrium as a byproduct of the processing of tailings for zircon (U.S. Bureau of Mines, 1994). Bastnaesite is currently mined as a primary mineral for rare earths at Mountain Pass, California, but yttrium concentrations in these ores are small.

Monazite is known in Colorado in pegmatites, from a few vein deposits, and as a minor constituent of black sands recovered from many of the State's gold placer deposits. Monazite has not been recovered from these deposit types. The only location from which monazite has been commercially recovered in Colorado is the Climax Mine, Lake County, where the mineral has been successfully obtained as a byproduct of the milling of large quantities of molybdenite ores (Eckel, 1961). Monazite recovered at Climax is most likely an accessory mineral in Precambrian igneous and metamorphic rocks hosting molybdenum-tungsten-tin ores (Wallace et al., 1968).

Bastnaesite occurs in some of Colorado's pegmatite deposits. Other rare-earth metals, notably cerium and lanthanum, have been obtained from this mineral, however, low yttrium contents in bastnaesite preclude recovery of this element from the small amounts of ore involved in the mining of pegmatite deposits.

Other yttrium-bearing minerals occur in Colorado's pegmatites deposits. The oxide minerals, euxenite and fergusonite, contain thorium, niobium, tantalum, titanium, and cerium-group rare-earth metals, all of which have been obtained in small quantities from pegmatite deposits. The yttrium-phosphate mineral, xenotime, is rare in Colorado's pegmatite deposits. This mineral commonly contains other rare earths, uranium, and thorium. The rare silicate of beryllium and yttrium, gadolinite, occurs in a number of pegmatites and has been produced as a source of both metals. Colorado produced small quantities of gadolinite in 1910 (Eckel, 1961).

Yttrium consumed domestically in 1993 was imported as compounds or derived from imported concentrates. The metal is used as a phosphor in color televisions and computer monitors, fluorescent lights, temperature sensing, and in X-ray intensifying screens. Yttrium is also used as a stabilizer in zirconia, for use in wear resistant and corrosion resistant cutting tools, seals and bearings, high-temperature refractories for continuous casting nozzles, jet engine coatings, oxygen sensors in automobile engines. Yttrium also has uses in electronics, lasers, glass, superalloys, and high-temperature superconductors (U.S. Bureau of Mines, 1994).

Zinc (Zn)

Zinc has been an important commodity to the economy of Colorado throughout the State's mining history. The metal ranks fourth in total dollar value of metallic elements produced, subordinate only to molybdenum, gold, and silver. Colorado zinc production continues to the present with 1993 figures reported at 13,500,000 pounds. This production came from Asarco Inc's. Black

Cloud Mine, Leadville district, Lake County, and was recovered concurrently with lead, silver, and gold. All of Colorado's zinc production has come from the mining of polymetallic (complex) ores, sought not only for their zinc content but for contained gold, silver, and other base metals.

The zinc-sulfide mineral, sphalerite, and its oxidation products, the zinc-carbonate, smithsonite, the hydrous zinc carbonate, hydrozincite, and the hydrous zinc silicate, hemimorphite, have accounted for the total of Colorado zinc production. Sphalerite is ubiquitous in the Colorado Mineral Belt, occurring as a constituent in nearly every known metallic-ore deposit. Sphalerite also occurs in many of the State's pegmatite deposits, and is a minor constituent of the Yule Marble, widely used as a decorative building stone (Eckel, 1961).

Sphalerite ores from Colorado may represent a future source of the trace metals cadmium, gallium, germanium, indium, and thallium. These trace metals, all of which have modern usage in high-technology applications, occur as minor constituents in zinc ores in various places worldwide. Some cadmium has been recovered from sphalerite ores mined in the Leadville district, Lake County. Sphalerites from other Colorado mining districts have not been assessed for trace metal contents. As world markets for these trace metals evolve, Colorado sphalerite ores may take on a new significance other than solely as a source of zinc.

Domestic consumption of zinc in 1993 consisted of: galvanizing (47%); zinc-based alloys (21%); brass and bronze (13%); and other (19%) (U.S. Bureau of Mines, 1994).

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Location Map and Descriptions of Metal Occurrences in Colorado with Notes on Economic Potential

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