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THE GEOLOGY AND OCCURRENCE OF CRITICAL STRATEGIC METALS (CHROMIUM, COBALT, MANGANESE, AND PLATINUM) IN WYOMING

by

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Introduction

In addition to Wyoming's vast energy resources, the State contains a diverse, but untapped assemblage of strategic minerals. Although known occurrences of these strategic minerals are numerous in Wyoming, the extent and grade of these deposits in most cases is unknown.

The Council of Economics and National Security in 1980 defined a strategic mineral as: "any mineral neither found nor produced in the United States in sufficient quantities to sustain the Nation during a period in which the security and/or economy of the country is threatened by a foreign power..." The Office of Technology Assessment (1985) further defined a strategic mineral as "...one for which the quantity required for essential civilian and military uses exceeds the reasonably secure domestic and foreign supplies, and for which acceptable substitutes are not available within a reasonable period of time."

Based on these descriptions, the definition for a strategic mineral is somewhat nebulus, and the strategic minerals will vary through time depending on the economic state of the United States, on technological advances in geology, mining, and metallurgy, and on the availability of the various mineral resources.

Some strategic minerals and metals listed by the U.S. Bureau of Mines (Council on Economics and National Security, 1980, appendix 7) include: aluminum, antimony, cadmium, chromium, cobalt, columbium-tantalum, copper, diamonds, fluorite, gold, iron ore, lead, manganese, mica sheets, nickel, platinum, silver, strontium, tin, titanium, tungsten, vanadium, and zinc. To consider some of these minerals and metals as strategic is questionable because of their abundant supply in the United States. Consequently, the Office of Technology Assessment (1985) further refined this list by listing the following important strategic minerals and metals: bauxite, beryllium, chromium, cobalt, columbium-tantalum, diamonds, graphite, manganese, platinum, rutile, tin, and vanadium.

Of greatest concern in the United States are "critical" strategic metals which include chromium, cobalt, manganese, and platinum group metals. These metals are considered critical because of their important civilian and military uses and because of their small known resources and supplies in the United States. In 1979 the United States imported 90% of its chromite, 98% of its manganese ore, 98% of its cobalt, and 89% of its platinum group metals (Velocci, 1980). In 1982, the United States still produced no chromium or cobalt, only 4,000 tons of manganese, and 9,000 ounces of platinum. In that same year the Nation imported 65% (147,969 tons) of its chromium, 52% (6,728 tons) of its cobalt, 55% (269,740 tons) of its manganese, and 48% (1,194,564 ounces) of its platinum from the Soviet Union and central and southern Africa (Office of Technology Assessment, 1985).

While the occurrence of these four critical strategic minerals in Wyoming is the subject of this paper (Figure 1), it must be realized that Wyoming also has numerous occurrences of many other strategic mineral resources in addition to these critical strategic minerals (see Osterwald and others, 1966; Harris and others, 1985). For example, Wyoming has one of the largest low-grade aluminum-titanium-vanadium deposits in the United States locked up in the 350-square-mile Laramie Range anorthosite batholith. But with the present market conditions and current technology, this deposit is not commercially feasible to mine. Wyoming also has several diamondiferous kimberlite intrusives in the Colorado-Wyoming State Line district. The only other locality where diamonds have been reported

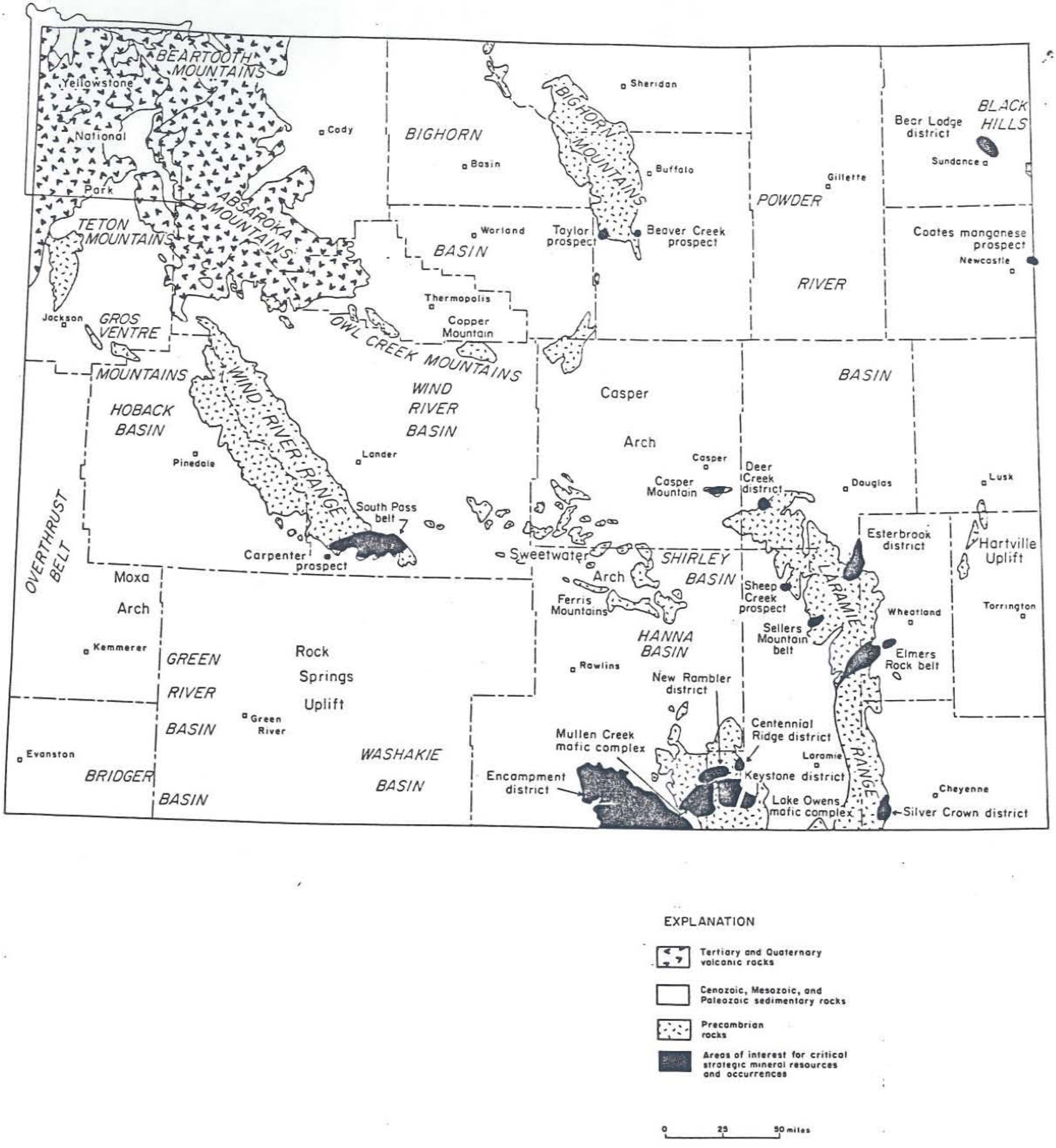

Figure 1. Areas of interest for critical strategic minerals in Wyoming.

in situ in the United States is at Murfreesburo, Arkansas. In addition, Wyoming has significant strategic mineral resources of low-grade copper, gold, beryllium, columbium-tantalum, iron, and tungsten.

Chromium

Chromium (Cr) is a critical strategic metal with important civilian and military applications. Its major use is as an alloying agent in steel to increase the hardness, strength, and corrosion resistance of steel. It is essential for the production of stainless steel, bearings, tools, and automobile components. Its major military applications are in the manufacture of hard chrome steel and jet engine components. Industrial uses include refractory bricks for metallurgical furnaces, photography, paints, and dyes.

The principal ore mineral of chromium is chromite, a black, submetallic weakly magnetic spinel with the general formula $(Mg, Fe^{2+}) (Cr, Al, Fe^{3+})_2 O_4$. The Cr/Fe ratio varies in the chromites and the higher ratios (2.8 and greater) are preferred for metallurgical purposes (Edwards and Atkinson, 1986). Other chrome-bearing minerals reported in Wyoming include fuchsite (a chrome muscovite), chromian diopside, and chromian chlorites (kammererite and wolchonskoite).

Chromite is primarily associated with ultramafic rocks. The average ultramafic rock contains 0.2% chromium, whereas mafic rocks contain an average of only 200 ppm chromium (0.02%) (Krauskopf, 1967, p. 588). Shales average about 90 ppm chromium (Krauskopf, 1967, p. 592). Chromium values generally increase with increasing magnesia (MgO) content in the mafic and ultramafic rocks. Additionally, nickel, platinum group metals, vanadium, copper, and zinc are often associated with and may be enriched in the MgO-rich rocks. Because of the ultramafic nature of the host rocks, many chromite deposits may be hosted by, or associated with, asbestos, talc, and serpentine. In addition to this assemblage of metals and minerals, significant gold is often spatially associated with the ultramafic rocks, particularly in greenstone belts. This association is believed to be genetic (Pyke, 1975; Groves and Hudson, 1981; Hausel, 1987).

Many chromite deposits can be classified as one of the following: (1) layered mafic complexes, (2) podiform ophiolite deposits, (3) komatiitic deposits, and (4) chromite placers. The layered complexes, are by far the most important deposits in the world, however, the low Cr/Fe ratios of the chromite in these occurrences make them less attractive for metallurgical requirements. The podiform deposits are much smaller, but produce chromite with higher Cr/Fe ratios that average about 3, which is better suited for metallurgical processes. Worldwide, the ultramafic komatiites host very low-grade, uneconomic, chromium occurrences. These rocks have such low-grades that they have no economic value except where they are enriched in nickel or possibly where the chromium has been remobilized. At a few localities in Wyoming, such rocks may have been upgraded by secondary processes. Chromite placers are of minor importance.

Presently, the United States is vulnerable to supply shortages of chromium because much of the imported metal is purchased from South Africa, the Soviet Union, and the Phillipines. Approximately 97% of the world's reserves are contained in just two layered mafic complexes known as the Bushvelt Complex in South Africa, and the Great Dike in Zimbabwe. Much smaller, but still significant reserves also occur in podiform deposits located in the Ural Mountains of the USSR, and also in Albania, the Phillipines, Turkey, and India. In 1982, approximately 55% of the world's chromite was mined from these smaller, high-grade (28 to 44% Cr_2O_3) deposits. The United States also has numerous podiform chromite occurrences along the west coast (Wetzel, 1986), but these are poorly evaluated and appear to be relatively small.

In Wyoming, anomalous chromium has been detected in ultramafic schists of apparent komatiite parentage in the South Pass, Sellers Mountain, Elmers Rock, and Seminoe Mountains areas. Significant chromite occurs in ultramafics in fragmented Archean supracrustals of possible greenstone belt origin in the Casper Mountain and Deer Creek areas. Although chromite has not been reported in layered mafic complexes in the Medicine Bow Mountains, these have not been fully evaluated and are considered reasonable exploration targets for both stratiform chromite and platinum. No chromite placers are known in Wyoming although the geography surrounding the Deer Creek deposit in the northern Laramie Range suggests a potential for chromite placers in this region. No deposits in Wyoming have yet been classified as podiform ophiolites.

Layered mafic intrusives are the greatest source of chromium in the world. These deposits are restricted to the stable cratons of the Precambrian, but only the older intrusives (2.0 to 2.7 billion years old) are known to host economic mineralization (Edwards and Atkinson, 1986).

Many of the layered complexes have been emplaced in gneissic basement complexes although the Stillwater complex of Montana and the Bushvelt complex in South Africa intrude supracrustals (Edwards and Atkinson, 1986). The Mullen Creek and Lake Owens layered complexes in the Medicine Bow Mountains of Wyoming intrude Proterozoic volcanogenic gneisses. These Wyoming complexes are interpreted to be about 1.8 billion years old (Karlstrom and others, 1981).

Layered mafic complexes are divisible into a lower ultramafic series and an upper mafic series. When found, chromite in these intrusives normally occurs in chromitite layers of variable thickness (1/4 inch to 3 feet) within the ultramafic portion of the complex. The chromitite layers may consist of greater than 50% chromite with interstitial olivine, pyroxene, and plagioclase confined to pyroxenitic and anorthositic layers. Anomalous platinum may also occur in these layers.

Podiform chromite deposits are essentially restricted to ophiolite complexes. With few exceptions, ophiolites are restricted to the Phanerozoic. Ophiolites are interpreted as fragments of the ocean floor tectonically emplaced into a continental environment during orogenesis. They consist of pillow basalts, sheeted dike complexes, peridotites, and pyroxenites.

Ophiolitic chromite deposits occur as tabular masses associated with peridotites (dunite, harzburgite, and wehrlite) and pyroxenites. According to Edwards and Atkinson (1986), chromite is generally restricted to the top of harzburgite (a peridotite consisting of olivine and orthopyroxene) zones in the ophiolite complexes.

To date, no deposits in Wyoming have been classified as podiform. However, the basal ultramafic-mafic metaigneous rocks of the State's greenstone belts exhibit characteristics of ophiolites even though they are Archean (>2.5 billion years old) rather than Phanerozoic in age. Harper (in press) for example, mapped a series of rocks along the northwestern flank of the South Pass greenstone belt which he interpreted to represent a dismembered (>2.8 billion years old) ophiolite. This unit consists of serpentinite, talc-tremolite schist, and metabasalt. The serpentinites and ultramafic schists have compositions approximating komatiite (Hausel, 1987).

Komatiites are primitive basaltic to peridotitic volcanic rocks with high magnesium, chromium, and nickel values, and high CaO/Al_2O_3 ratios. These rocks also exhibit anomalously low titanium and alkali contents. They are restricted to Archean terrains.

These unusual rocks have been recognized for their commercial nickel mineralization in Western Australia. In the Kambalda region of the Yilgarn block of Western Australia, economic nickel mineralization occurs in association with gossans along the basal contacts of some ultramafic flows. In addition, these cumulus zones contain anomalous platinum, copper, zinc, and chromium although chromium may be slightly depleted in the cumulates compared to the upper portions of the flows (Groves and Hudson, 1981). Overall, these rocks carry relatively consistent uneconomic chromium values ranging from 0.1% to 1%. Metakomatiites (serpentinites and talc-actinolite schists) in the South Pass, Seminoe Mountains, and Elmers Rock greenstone belts of Wyoming contain Cr_2O_3 concentrations commonly greater than 0.1% but less than 1.0%. But in the Casper Mountain and Deer Creek regions, relatively high-grade chromite is found in talc-actinolite schist.

Alluvial and placer chromite deposits can result from the weathering of a chromite-bearing rock. Chromite has a relatively high specific gravity (4.3 to 4.6) and is resistant to chemical and physical breakdown and disintegration which favors its concentration in placers. Although no significant placer chromite has been reported in Wyoming, the historic Deer Creek mine in Converse County is located in a steep-sided valley draining into Deer Creek. Such circumstances are favorable for placer development.

Worldwide, placer chromite deposits produce only a minor amount of the strategic mineral although mining and production expenses for these deposits are relatively low. Commercial placers occur in Cuba, New Caledonia, and Zimbabwe. Coastal marine black sand chromite placers are rare but have formed along the Pacific coast of California and Oregon (Wetzel, 1986) and in the Terpeniya Bay of the Soviet Union (Smirnov and others, 1983). Also, Houston (1969) reported that Cretaceous-age paleoplacer black sandstones in Wyoming contain a variety of complex iron-titanium oxides along with ilmenite, titaniferous magnetite, and chromite. Some of these also contain gold values as high as 1.3 ppm.

Exploration for chromite is best done by detailed geologic mapping that concentrates on specific ultramafic horizons. The ore horizons in mineralized mafic layered complexes are anorthosites and pyroxenites. Dunites, harzburgites, and serpentinites are important chromite-bearing host rocks in podiform deposits. Geophysical exploration is generally inconclusive, but a combination of complex resistivity and seismic surveys have identified subtle anomalies over some chromitite layers (Edwards and Atkinson, 1986).

Based on the available data, it is apparent that the greatest potential for large tonnage chromite deposits in Wyoming occurs in the large, layered, mafic complexes of the Medicine Bow Mountains. Low-grade chromite has been recognized in ultramafic schists and serpentinites in the Elmers Rock, Casper Mountain, and Deer Creek Archean supracrustal belts suggesting that the metakomatiites(?) or intrusive equivalents may be potential sources for commercial chromitite. Little is known about these deposits and they are in great need of further study.

ALBANY COUNTY

I. Laramie Range

Elmers Rock greenstone belt; This includes a large segment of metamorphic terrain in T.22N.-T.23N., R.70-72W. of the central Laramie Range north of Sybille Canyon. The Elmers Rock greenstone belt is a synformal sequence of metamorphosed Archean sedimentary, volcanic, and plutonic rocks that trend north-northeasterly across the central Laramie Range (Graff and others, 1982; Graff and Hausel, 1986). This belt of metamorphics consists of a lower ultramafic to mafic group of rocks overlain by metasediments. These rocks of the greenstone belt are between 2.54 and 3.02 billion years old (Graff and others, 1982).

The lower unit is dominated by mafic amphibolite with a thin (150 to 500 feet) belt of actinolite-chlorite schists of komatiite affinity. Samples of these schists contain slightly anomalous chromium (2,700 ppm Cr) (0.27%) and 1,600 ppm Ni (0.16%) (Graff and others, 1982).

However, along the northwestern edge of the greenstone belt north of Halleck Canyon (SE/4 sec. 24, T.22N., R.72W.) in the vicinity of Mill Creek, disseminated chromite and chromite veinlets occur in serpentinite and possibly talc tremolite schist in an area about 200 feet in diameter. Additional chromite may be hidden by soil cover.

One sample collected from a chromite vein in this area was highly anomalous and assayed 9.3% chromium. A sample of rock containing disseminated chromite assayed 0.87% chromium. Anomalous molybdenum (?), copper, and nickel were also detected (Fields, 1963).

Iron Mountain district; T.18-21N., R.71-72W.; Scattered titaniferous-magnetite pods, lenses, and disseminations in the 350-square-mile Laramie Range anorthosite batholith contain enormous tonnages of titanium, iron, and vanadium. Just one of many of these deposits, the Iron Mountain deposit (secs. 22, 23, 26, and 27, T.19N., R.71W.), contains 5.5 million tons of inferred reserves of titaniferous magnetite (Osterwald and others, 1966).

Dietz (1932) reported one analysis of titaniferous magnetite from the Iron Mountain deposit yielded 2.45% Cr_2O_3. If Dietz's results can be verified, this region could include a tremendous resource of very low-grade chromium and other strategic metals.

Sellers Mountain belt; T.25N., R.73W.; The Sellers Mountain area, located in the vicinity of Garrett, Wyoming, is possibly a fragment of a greenstone belt or a supracrustal outlier. This region contains similar stratigraphic units as the Elmers Rock belt and also includes banded iron formation, asbestos, and gold-arsenic-antimony mineralization. Langstaff (1984) reported talc-tremolite-chlorite schists and metaperidotite of komatiite affinity which contained as much as 0.22% nickel and 0.73% chromium. Gold in the belt has been reported in association with arsenopyrite and berthierite along a contact between micaceous quartzite and amphibolite (Hausel, 1986a, p. 53).

II. Medicine Bow Mountains

Keystone district (Figure 1); A number of gold-copper mines and prospects were developed along northwesterly-trending shears near the margin of the Keystone quartz diorite. The quartz diorite is sandwiched between the Mullen Creek mafic complex on the west, and the Lake Owens mafic complex on the east. One of the mines, the Cuprite mine, contained anomalous copper, gold, silver, cobalt, and chromium (Currey, 1965).

Cuprite mine; sec. 11, T.14N., R.79W.; Located on the Albany-Cuprite trend. A 954-foot tunnel was driven into quartz-feldspar gneiss near the northwestern margin of the Keystone quartz diorite. The tunnel followed the mineralized trend and a 65-foot shaft was sunk near the apex of the trend. Native copper, cuprite, pyrite, chalcopyrite, and chalcocite were identified in the mineralized rock. Assays were reported to range from 3 to 28% copper, a trace to 2.56 oz/ton gold, a trace to 2.0 oz/ton silver, with chromium and cobalt values (Currey, 1965).

Lake Owens mafic complex (Figure 1); T.13-14N.; R.77-78W.; The Lake Owens mafic complex is a large, circular, layered intrusive that includes a roughly 21-square-mile area, though much of it is hidden by Quaternary and Tertiary cover and remains unexplored. The complex is relatively well-preserved with an estimated age of 1.8 billion years old (Karlstrom and others, 1981, p. 96).

Houston and others (1968) recognized two generalized zones in the Lake Owens complex -- (1) olivine-bearing zones consisting of troctolite (a gabbro composed chiefly of calcic plagioclase and olivine), olivine gabbro, and olivine norite, and (2) gabbroic zones consisting of gabbro and norite. Layers of anorthosite and metaperidotite also occur in the complex. Traces of copper (700 ppm maximum), nickel (300 ppm maximum), and platinum (0.15 ppm maximum) have been detected in the complex. The highest platinum values were detected in a leucotroctolite unit containing anorthosite and leuconorite (Houston and Orback, 1976). No chromium values were reported although the complex is incompletely explored.

CARBON COUNTY

I. Medicine Bow Mountains

Mullen Creek mafic complex; The Mullen Creek mafic complex includes about 60 square miles of surface area in T.13-14N., R.79-81W. The northern and northwestern margins of this intrusive are cut by shear zone cataclastics of the Mullen Creek-Nash Fork shear zone, and portions of the complex have been intruded by 1.5 to 1.7 billion year old granite. The complex is interpreted to be about 1.8 billion years old. The complex intrudes Proterozoic-age hornblende gneiss (Houston and others, 1968).

The complex consists of amphibolite-grade metamorphosed massive to well-layered gabbro, leucogabbro, anorthositic gabbro, anorthosite, and pyroxenite differentiates (Donnelly, 1979). A few magnetite-rich and local sulfide-rich zones occur in the complex and several gold and platinum mines and prospects lie along the edges of the complex (McCallum and Kluender, 1983). The most notable of these is the New Rambler mine located in a shear zone that truncates the mafic complex on the north. The New Rambler produced platinum and palladium during the early 1900s (see PLATINUM).

Donnelly (1979) reported samples of gabbro and pyroxenite collected from the complex contained traces of chromium. The highest value reported by Donnelly (1979) was only 1,000 ppm (0.1%) chromium for a metapyroxenite. McCallum and Kluender (1983), however, reported several samples of metapyroxenite which contained 5,000 ppm (0.5%) chromium. Samples of gabbro collected in the vicinity of Boat Creek along the Golden Eagle and Natures Mint trends near the western margin of the mafic complex assayed as high as 6.2 ppm gold (R.E. Jones and J.T. Roberts, personal communication, 1987). Two veins cutting this gabbro have produced selected samples with as much as 280 ppm and 800 ppm gold, respectively (McCallum and Kluender, 1983).

CONVERSE COUNTY

I. Laramie Range

Deer Creek mine; sec. 11, T.31N., R.77W.; Located 16 miles southwest of Glenrock in a thin serpentinite exposed along the steep-walled valley of Deer Creek Canyon (Figure 1). Chromite occurs in the serpentinite at intervals over 150 feet in a 2- to 5-foot wide layer (Spencer, 1916, p. 78). The serpentinite trends N.75°W. and dips 45°SW and is traceable for 1,000 feet west of Deer Creek. The serpentinite also extends several hundred feet to the east (Beckwith, 1939). Although chromite placers have not been reported in Deer Creek, based on the location of the chromitite in the canyon, conditions appear to be favorable for placer development.

Chrome chlorites (kammererite and wolchonskoite) occur locally forming veins and lining cavities in the chromite. Assays of the ore yielded 35 to 45% Cr_2O_3 with 16 to 21% iron oxide (Spencer, 1916; Beckwith, 1955).

In 1908, at least 700 tons of ore averaging 35% Cr_2O_3 were mined from the property (Beckwith, 1939). During the First World War (1918-1920), another 1,594 tons of ore containing 35 to 45% Cr_2O_3 were mined. Reserves have not been delimited although Dietz (1932) estimated at least 2,500 tons of 40% Cr_2O_3 ore remained exposed on the surface.

A short distance south in sec. 15, T.31N., R.77W. on the north side of west fork of Deer Creek is another serpentinite lens containing some asbestos and vermiculite (Beckwith, 1939). In addition, several serpentinites with asbestos and talc occur both east and west of the Deer Creek mine (Harris and others, 1985; Gable, 1987) indicating potential for additional chromite deposits in this region.

FREMONT COUNTY

I. Wind River Mountains

South Pass greenstone belt; The South Pass greenstone belt lies at the southern tip of the Wind River Mountains (Figure 1) and includes about 150 square miles of exposed metamorphic terrain and a large region overlain by a thin Tertiary cover. The greenstone belt consists of low- to moderategrade metamorphosed sedimentary, volcanic, and plutonic rocks intruded along the eastern and northwestern flanks by 2.6 billion year old granite and granodiorite. The youngest Archean supracrustal unit is at least 2.8 billion years old (Stuckless and others, 1985). The belt has numerous gold mines in shear zones hosted by metagreywacke and orthoamphibolite (Bayley and others, 1973; Hausel, 1986b) that are spatially associated with actinolite schist, talc-tremolite-chlorite schist, and serpentinite of komatiite affinity (Hausel, 1987).

The ultramafic schists, along the eastern greenstone belt margin, were examined by Hausel (1987). They contain anomalous chromium and traces of nickel. Values as high as 0.87% chromium and 0.17% nickel were obtained from serpentinites and talc-tremolite schists in the Lewiston Lakes area (T.29N., R.97-98W.). No platinum or palladium were detected.

Dietz (1932, p. 93) reported chromite was found in Rock Creek of the South Pass-Atlantic City district along the northwestern flank of the greenstone belt. Similar ultramafic schists to those found along the eastern greenstone belt margin also occur near the headwaters of Rock Creek. For example, Harper (in press) mapped metabasalts, metadiabases, talc schists, and serpentinites in this region. One of these serpentinites, known as the Fire King deposit (NW/4 sec. 26, T.30N., R.100W.), was mined for asbestos prior to 1920 (Beckwith, 1939). No chromite was reported.

In the Anderson Ridge region near the western edge of the South Pass greenstone belt, pods of ultramafic schist in gneiss country rock (NE/4 sec. 24, T.29N., R.102W.) contain minor chromium and nickel values (Cr=0.38%; Ni=0.17%).

LINCOLN COUNTY

I. Overthrust belt; Phosphorites and phosphatic shales of the Phosphoria Formation are hosts to a variety of anomalous metals including chromium, vanadium, gold, and silver. A number of these localities have been described in the literature, and are reviewed by Harris and Hausel (1984).

Anomalous concentrations of chromium were detected in the Meade Peak Member of the Phosphoria Formation by Desborough (1977) in the Mabie Canyon area of Idaho. Reported values ranged from 0.25% to 1.7% chromium. Motooka and others (1984) also reported anomalous chromium in the Phosphoria Formation in the Jackson Hole area, but again these values, although anomalous, are very low.

NATRONA COUNTY

I. Laramie Range

Casper Mountain; SW/4 sec. 16, SE/4 sec. 17, NE/4 sec. 20, T.32N., R.79W.; Chromite lenses, pods, and disseminations occur in a Precambrian tremolite-talc-chlorite schist on Casper Mountain along a contact between gneiss and granite (Figure 1). The mineralized schist trends N60°E and has a near vertical dip (Burford and others, 1979). The main body of chromite-bearing schist is 2,500 feet long and 350 feet wide (Beckwith, 1939; Hausel and Glass, 1980). A smaller lens, 400 feet east of the main lens, is 750 feet long and 350 feet wide (Horton and Allsman, 1949). The schist averages about 2% chromium oxide (Cr_2O_3), but contains bands that run 5 to 25% Cr_2O_3. Analyses of chromite concentrates from the main deposit produced the following results:

Oxide (%)	1	1	1	2	2	2
Cr_2O_3	44.74	46.6	26.6	26.7	13.7	3.6
FeO	18.05	36.0	63.0	--	--	--
Fe_2O_3	18.22	--	--	--	--	--
Al_2O_3	12.28	--	--	--	--	--
MgO	5.24	--	--	--	--	--
MnO	0.19	--	--	--	--	--
CaO	0.20	--	--	--	--	--
SiO_2	0.64	--	--	--	--	--
TiO_2	0.24	--	--	--	--	--

(1) Analyses from Horton and Allsman (1949).
(2) Analyses from Beckwith (1939).

Trenching and drilling by the U.S. Bureau of Mines delineated inferred reserves of 575,000 tons of chromite averaging 8.7% Cr_2O_3, and a total low-grade resource of 4,160,000 tons of 2.5% Cr_2O_3 (Julihn and Moon, 1945). These resources are calculated to a depth of 95 feet, and drilling indicates mineralization occurs to depths of at least 480 feet (Daellenback, 1985). Based on the stratiform nature of the mineralization and the steep dip, mineralization may continue to even greater depths.

Cobalt

Cobalt has many important uses, but its largest and most critical use is in superalloys used in gas turbines for aircraft. These superalloys require high strength at high temperatures. Cobalt is also used as a hardening agent in steels. Some of its other primary uses include magnets, high-speed carbide tools, catalysts in petroleum refining, and blue paint pigments. Approximately 98% of the metal used in this country is imported.

Cobalt is generally recovered as a by-product from copper and nickel ores. Its average crustal abundance is 20 ppm, but it is enriched in mafic and ultramafic rocks such that the average ultramafic rock contains 270 ppm cobalt (Krauskopf, 1979). Cobalt is recovered from a number of different deposit types in the world which include (1) hypogene mineralization associated with mafic intrusives; (2) contact metamorphics associated with mafic rocks; (3) nickel laterites; (4) massive sulfides in metamorphic rocks; (5) hydrothermal; and (6) stratabound deposits. Hypogene deposits associated with mafic intrusives include such deposits as the Sudbury district of Ontario. This large iron-nickel-copper sulfide deposit contains average cobalt values of only 700 ppm. The ore mineralogy consists of pyrrhotite, pentlandite, pyrite, marcasite, magnetite, cobaltite, and gersdorffite as pods, veins, and disseminations in a layered norite, quartz diorite intrusive of Precambrian age.

Similar deposits include minor cobalt in pyrrhotite hosted by mafic intrusives. Cobalt concentrations in some of these gabbroic intrusives range from 0.003 to 0.24% cobalt (Vhay and others, 1973). Vhay and others (1973) also report peridotite and serpentinite metamorphosed to amphibolite facies contain anomalous cobalt and nickel in the Lynn Lake and Thompson-Moak Lake regions of Manitoba.

Contact metamorphic deposits include magnetite, chalcopyrite, and cobaltiferous pyrite deposits formed in carbonates along the contact of some mafic dikes. Although important at some locations in the world, these and the lateritic deposits probably have no significance in Wyoming.

Massive sulfide mineralization in metamorphic rocks include pyrite-pyrrhotite massive sulfide deposits in metamorphic rocks with andesitic affinity. These are mined for other metals, and cobalt is recovered as a by-product. Cobalt in these deposits occurs in minor concentrations (0.02 to 0.07% Co).

Hydrothermal deposits have been important sources of cobalt, worldwide. Cobalt-bearing vein deposits in the Blackbird district, Idaho, average 1.6% copper and 0.6% cobalt with traces of nickel and precious metals (Vhay and others, 1973). Many of these vein deposits are quite complex (Co-Ni, Co-Ni-Ag, Co-Ni-Bi-Ag-U, and Co-Ni-Cu-Pb-Zn) and are generally associated with granites although the host rocks include serpentinites, and sedimentary and metamorphic rocks (Smirnov and others, 1983).

Some Mississippi Valley deposits which formed from low temperature (125°C) brines, occur in Cambrian to Pennsylvanian carbonates on the flanks of broad domes. In some districts, lead, zinc, iron, and copper sulfides with cobalt and nickel occur in sufficient amounts to economically recover the cobalt.

Stratabound deposits include the great copper-cobalt deposits of Zaire and Zambia. These contain chalcopyrite, bornite, and chalcocite accompanied by cobalt, nickel, zinc, silver, and cadmium. The deposits are confined to depressions filled with rhythmically interbedded sandstones, shales, and dolomites of lagoon-delta and near-shore facies with high carbon content (Smirnov and others, 1983). Average ores contain 3.5% copper and 2.0% cobalt (Vhay and others, 1973). The source of the metals is presumably derived from the erosion of a nearby, uplifted, metal-rich terrain.

Very little cobalt has been reported in Wyoming, and the little that has been reported is generally in trace amounts associated with mafic intrusives. Traces of cobaltite ($CoAsS$), erthyrite [$(Co, Ni)_3(AsO_4)_8 \cdot 8H_2O$], and linnaite ($Co_3S_4$) have been identified in Precambrian copper-gold ores in southern Wyoming. Because of its similar habit to pyrite and arsenopyrite, cobaltite could be more common in Wyoming and may have been overlooked at some localities.

ALBANY COUNTY

I. Medicine Bow Mountains

Keystone district

Cuprite mine; NW/4 sec. 11, T.14N., R.79W.; The Cuprite mine produced both copper and gold and reportedly also had cobalt and chromium values (see also CHROMIUM) (Currey, 1965).

Douglas mine; SE/4, sec. 9, T.14N., R.79W.; A seven-foot-wide mineralized zone was mined for native copper, copper carbonates, chalcopyrite, chalcocite, gold, and cobaltite (Currey, 1965). The mine workings were destroyed during the construction of the road along the western bank of Douglas Creek.

Medicine Bow Mines Company; At Holmes. Cobalt was reported in the copper-gold ores in this area (Beeler, 1906a; Sanford and Jones, 1914, p. 215).

CARBON COUNTY

I. Ferris Mountains

SE/4 sec. 32, T.27N., R.87W. A sample collected from a four-foot-wide quartz-sulfide vein at this locality yielded copper (>10,000 ppm), arsenic (3,000 ppm), cobalt (3,000 ppm), lead (100 ppm), silver (5 ppm), and gold (0.2 ppm). Some cobaltite occurs with chalcopyrite (Master, 1977, p. 52).

SE/4 sec. 4, T.26N., R.87W. A quartz-sulfide vein less than three feet thick assayed >10,000 ppm copper with a trace of cobalt (100 ppm); (Master, 1977, p. 52).

NW/4 sec. 30, T.27N., R.88W. A one- to two-foot-thick vein assayed >10,000 ppm copper, 10 ppm silver, 50 ppm tungsten, 20 ppm molybdenum, 200 ppm nickel, 100 ppm cobalt, and 0.03 ppm gold (Master, 1977, p. 53).

II. Sierra Madre

Encampment Mining district; (see Hausel, 1986c for description of the district).

The Encampment district includes hundreds of mines and prospects in the Sierra Madre, Wyoming. Many of these mines were operated for copper and (or) gold. Trace amounts of cobalt have been found in association with some mafic dikes and pods. In general, the Sierra Madre is a Laramide anticlinal uplift cored by Proterozoic miogeoclinal metasediments to the north separated from eugeoclinal metavolcanics and gneisses to the south by a major shear zone.

Blue Bell mine; The ore at the Blue Bell mine was reported to contain 5% cobalt (Armstrong, 1970, p. 2). No location is given for the mine.

Charter Oak mine; sec. 24, T.14N., R.85W.; The mine was developed on a quartz vein located on the east flank of a broad syncline in granite gneiss, schist, and diorite country rock. The vein contains copper sulfides which extend into the adjacent fractured country rock. Chalcopyrite, chalcocite, bornite, and azurite were identified in the mine by Spencer (1904, p. 82-85).

The vein strikes northerly and dips to the east. The mineralized rock has been traced on the surface for two miles and varies in width from 14 feet at the Charter Oak shaft, to a maximum of 100 feet elsewhere. According to Beeler (1906a), an open cut exposed a huge ledge of mineralized diorite (diabase?) stained with copper carbonate. As much as 4% to 5% cobalt was reported in the ores (Armstrong, 1970, p. 2) with anomalous nickel (Paul J. Graff, pers. comm., 1985). The Charter Oak was sunk to a depth of 488 feet with more than 300 feet of drifts (Beeler, 1905, p. 21).

Creede property; N/2 sec. 10, T.14N., R.86W.; Located two miles northwest of Bridger Peak. Pyrrhotite, magnetite, and chalcopyrite with nickel and cobalt are localized along a contact between hornblende schist and a norite intrusive (Spencer, 1904, p. 54, 86).

Doane-Rambler mine; NE/4 sec. 25, T.14N., R.86W.; The Doane-Rambler mine was developed in Proterozoic-age Cascade Quartzite. The quartzite trends east-west, dips 65°N to 75°N, and is as much as 500 feet thick at the mine site. The mineralization is stratabound, and consists of chalcopyrite, bornite, chalcocite, covellite, malachite, azurite, and chrysocolla localized where bedding planes intersect fracture planes. The mineralization follows stratification in the quartzite (Spencer, 1904; Houston and others, 1975). Early reports indicate the Doane-Rambler ores contained some cobalt (Armstrong, 1970, p. 2).

Leighton-Gentry (Jack Creek) mine; SW/4 sec. 5, T.14N., R.86W.; A narrow gossan at the mine site is structurally overlain by four feet of crumbly mica schist which is in turn overlain by a thick norite sill. The footwall of the gossanous zone is a 11-foot-thick limy quartzite.

Pyrite, pyrrhotite, and chalcopyrite occur along bedding planes and are disseminated throughout the limy quartzite. Metalimestone below the quartzite is barren of sulfides. The rocks strike N80°W and dip 30°S. One assay gave 3.07% copper and 0.67% nickel and cobalt with a trace of zinc (Spencer, 1904, p. 87-88).

CONVERSE COUNTY

I. Laramie Range

Esterbrook district. The Esterbrook district lies in the northern Laramie Range. Granites intrude Archean supracrustals that may be part of a fragmented greenstone terrain. These supracrustals are generally described as hornblende schists although some pillow basalts have been reported in the district (George Langstaff, personal communication, 1985)

Three Cripples mine; NW/4 sec. 15, T.28N., R.71W.; The Three Cripples mine was developed on a northeast-trending, limonite-stained shear zone in schist. Dump samples collected by Spencer (1916) from the 96-foot shaft contained pyrrhotite with some chalcopyrite. A composite sample of 25 chips collected from different locations on the mine dump averaged 0.23% copper, 41.8% iron, and a trace of cobalt (Spencer, 1916). Hall (1909) reported pyrrhotite-bearing samples from the mine contained values in copper, gold, silver, and traces of nickel. Traces of sphalerite are also reported (Greeley, 1962).

Trail Creek mine; NW/4 SE/4 sec. 10, T.29N., R.71W.; Located 25 miles south of Douglas near the head of Trail Creek. Interlayered granite and schist strike northeast and dip gently to the northwest and are intruded by conformable diorite dikes. The granite is very siliceous and in places grades into quartz veins. The veins are stained by limonite and hematite, and locally contain masses of azurite and malachite with small amounts of sulfides. In places, inclusions of schist are incorporated in the veins (Beeler, 1903).

A small lens of uraninite cut by the Trail Creek adit was discovered in fresh unaltered hornblende schist wallrock at the intersection of north- and northeast-trending, vertical-dipping, shear zones. The uraninite is coated by erythrite $[Co_3 (AsO_4)_2 \cdot 8H_2O]$, and occurs as coatings along shear zones and as disseminations in hornblende schist (Guilinger, 1956).

LARAMIE COUNTY

Silver Crown district; Located on the eastern flank of the Laramie Range, 20 miles due west of Cheyenne. Copper-gold mineralization is localized in veins and in fault gouge in shear zones in metamorphosed volcanics and plutonic rocks of Proterozoic age (Klein, 1974). Erythrite (cobalt bloom) was discovered in the vicinity of Middle Crow Creek of the Silver Crown district. Analyses of some ore in the district also showed traces of linnaeite (Co_3S_4) (Aughey, 1886, p. 55).

MANGANESE

Manganese is a critical strategic metal for which the United States presently has no mine production. Essentially all of the manganese used in this country is imported with insignificant amounts recovered through recycling. Of the estimated world reserve base of manganese ore, 91.6 percent occurs in the Soviet Union and the Republic of South Africa. The remaining 8.4 percent is scattered between numerous deposits in several other countries. For manganese's major uses, there is no satisfactory substitute.

The principal use for manganese is in steel production for construction and machinery. Manganese is also used to produce pig iron and dry cell batteries, and it has various chemical applications (Jones, 1984).

Wyoming has no known manganese reserves and unfortunately little is known about the State's resources of this metal. In past years, however, some manganese ore was produced. Recorded production shows that at least 250 tons were mined in the State. Production could have been much greater, because conflicting reports on the Sheep Creek prospect in Albany County report production in hundreds of tons and also in thousands of tons. Osterwald and others

(1966) reported yearly production of manganese as follows:

Year	Tons
1917	33.7
1918	103.4
1919	"some"
1920	44.9
1943	67.4
1946	"some"

Manganese is common throughout the State as manganese oxide stains, which are composed of the minerals pyrolusite (MnO_2) and psilomelane [$BaMnMn_8O_{16}(OH)_4$]. When it occurs as stains, only trace amounts of the metal are present. The metal also occurs in veins forming irregular deposits, in residual clays, and as ferromanganese nodules in some Cretaceous shales. Some trace amounts of manganese have also been reported in vermiculite deposits (see Osterwald and others, 1966, p. 233-236).

The crustal abundance of manganese is about 0.1%. Felsic igenous rocks contain about 0.08% manganese and the average ultramafic rock contains manganese values of 0.19%. Greywackes are reported to contain an average of 0.08% manganese (Stanton, 1972).

The geochemistry of manganese (Mn) and iron (Fe) are similar which often results in their deposition together in some deposits. But because of slight geochemical differences, they are also found separate from one another. For example, iron oxides will precipitate at lower pH and at a lower Eh (at a given pH) than will manganese oxides.

In the Cuyuna district, Minnesota, iron was co-precipitated with manganese which resulted in the deposition of manganiferous iron formation containing as much as 20% manganese (Evans, 1980). However, iron formation from the South Pass-Atlantic City district in the Wind River Mountains contains essentially no manganese.

There are a number of types of manganese deposits in the world, but the world's largest deposits occur as sedimentary and residual deposits. Volcanogenic and hydrothermal deposits are also known but are economically unimportant.

Sedimentary deposits contain the greatest reserves of manganese in the world of which the USSR is the principal producer. Significant tonnages of sedimentary manganese are mined from the Nikopol Basin in the Ukraine where the ore averages 15 to 25% manganese, and from the Chiatura Basin in Georgia (USSR) where the ores average 35% manganese. Other sedimentary deposits are mined in South Africa, Gabon, India, Australia, and Brazil. Sedimentary deposits are generally separated into orthoquartzite-glauconite-clay associations and carbonate associations.

The orthoquartzite-glauconite-clay associations occur on stable Precambrian basements adjacent to uplifts. These deposits are interpreted to have been eroded from an uplifted volcanic terrain and deposited in the adjacent estuarine to shallow marine environment. The mineral deposits are flanked on one side by coarse clastics which lie between the mineral deposit and the source terrain, and flanked on the opposite side by argillaceous sediments. Glauconitic sand is often present at the base of the manganese deposit, and the ore itself consists of concretions and nodules of manganese oxide and carbonate in a silty to clay matrix. Progressing towards the marine side of the deposit, away from the uplift, the mineralized layer grades into dominantly greenish clays with occasional manganese nodules.

The carbonate associations occur in geosynclinal dolomite-limestone rocks, or within a stable basement platform. The Usa deposit (Cambrian) in southwestern Siberia, occurs in a thick dolomite-limestone sequence in a geosyncline. More than 3,000 feet of limestone and dolomite underlie the principal manganese deposits which are themselves interstratified in the carbonates. The ore consists principally of bituminous manganiferous carbonates and minor oxides (Stanton, 1972). Deposits of this type have not been recognized in Wyoming to date.

The cratonic type of manganese deposit occurs on eroded cratonic surfaces close to areas that were uplifted during the time of sedimentation. Here the succession generally consists of an ore-bearing unit sandwiched between terrigenous red beds. The ore-bearing unit consists of manganese oxide with carbonate and minor clay and sometimes gypsum. No deposits in Wyoming have yet been classified as cratonic types although some could potentially exist in the State.

A great majority of Wyoming's manganese deposits are residual and resulted from the weathering of manganese-bearing minerals from the Precambrian terrain. These deposits are located adjacent to the uplifted mountain ranges and most often occur as manganiferous oxides staining rocks and filling preexisting fractures. Since Evans (1980) stresses that spilites are good source rocks for manganese, these residual deposits may possibly be best developed adjacent to greenstone belts such as South Pass, the Seminoe Mountains, and Elmers Rock in Wyoming.

Although volcanic associated manganese deposits are the most widespread in the world, they are generally uneconomic. The most prominent volcanogenic type is manganiferous jasperoids in greenstone belts. The jasperoids are often regarded as highly siliceous hematitic iron formations (Stanton, 1972). No volcanic associated manganese deposits have been identified in Wyoming to date.

ALBANY COUNTY

Fox Creek area; T.13-14N., R.77W.; Three quartz veins in the NW/4 sec. 27, SW/4 sec. 32, T.14N., R.77W., and in the W/2 sec. 3, T.13N., R.77W. contain varying amounts of manganese oxide. Orback (1960, p. 97) indicated that pyrolusite and psilomelane comprised up to 20 percent of the veins.

Hutton Lake occurrences; sec. 21, T.14N., R.74.; Located south of Laramie along the Sand Creek Road. Several siderite nodules stained with manganese and ranging from a few inches to a few feet across were discovered along the edge of the Hutton Lake National Wildlife Refuge (Wayne Kinney, personal communication, 1982). The nodules occur in Cretaceous shales.

J.B.C. Mining; Located 44 miles northeast of Rock River (legal location not given). Shibler and Snedden (1949) reported psilomelane and pyrolusite to be interlayered with quartz and chalcedony in highly siliceous limestone. One assay by the U.S. Bureau of Mines showed 28.7% manganese, 43.4% silica, 1.35% iron, and 0.1% zinc.

Sheep Creek prospect; sec. 10, T.26N., R.75W.; Located four miles southeast of Marshall near the head of Sheep Creek. Jones (1921) reported that no ore had been shipped from this property at the time of his visit in 1917, but that 200 tons of 40% manganese ore were sitting on the mine dump. Later it was reported that several thousand tons of ore had been shipped (Anonymous, 1929).

The ore occurs as manganite and pyrolusite in two chert beds of the Casper Formation. The beds range from one to eight feet thick and average six feet thick. The ore occurs as manganese oxides in mammillary crusts and nodular aggregates entirely or partially replacing chert and small portions of the limestone wallrock. Cavities in the chert contain small quartz crystals on layers of manganite. Botryoidal clusters of wedge-shaped manganite and tabular barite crystals line some of the vugs (Jones, 1921).

CARBON COUNTY

Ak-Sar-Ben group; secs. 14 and 15, T.14N., R.80W.; Situated at the head of Iron Creek, a small tributary of French Creek on the western slope of the Medicine Bow Range. On the southwestern end of this group, an 80-foot shaft with crosscuts intersected a vein in schist country rock that was stained with iron oxide and contained considerable manganese and graphite according to Beeler (1906b).

CROOK COUNTY

Bear Lodge District

Caulkins McGuckin property; Located ten miles north of Sundance. Schack and Poole (1947) report pyrolusite and braunite $[(Mn,Si)_2O_3]$ occur with iron oxide in a vein hosted by rhyolite porphyry. An analysis of manganese material gave: Mn = 31.6 percent, Fe = 18.6 percent, SiO_2 = 5.2 percent, and Zn = 0.35 percent, (Schack and Poole, 1947, p. 38).

Hutchins Consolidated Mining property; secs. 17, 18, 19, and 20, T.52N., R.63W.; A massive vein of psilomelane and pyrolusite cuts across the property. Additionally, abundant northwesterly-trending fissures filled with quartz, fluorite, and limonite also cut across the property. Gold occurs in the country rock (Jamison, 1912).

Black Rock claim; Located about nine miles northeast of Sundance. Manganese oxides occur in altered porphyry. Two carloads of ore were shipped from the property that contained 40 percent and 44 percent manganese, respectively (Hagner, 1948).

FREMONT COUNTY

Carpenter prospect; sec. 35(?) T.28N., R.102W.; Located 52 miles south of Lander and two miles west of Pacific Springs. Pyrolusite is exposed in a 30-foot-deep pit sunk in poorly consolidated Eocene sandstones. Two analyses of a 12-foot thick bed of manganese oxide assayed 18% and 35% manganese. There are scattered showings of manganese for six miles to the southwest (Hagner, undated). This occurrence merits further investigation.

Marion Maxwell; Manganese occurring as either braunite or manganite has been reported in the Marion-Maxwell dike near Bonneville (Osterwald and others, 1966, p. 131). Bonneville lies a short distance south of Copper Mountain and north of Shoshoni.

Sec. 35, T.28N., R.102W.; Pyrolusite reportedly occurs in the matrix of arkosic conglomerate near South Pass (see Carpenter Prospect above). Assays give 19 to 35% manganese (Osterwald and others, 1966, p. 131).

JOHNSON COUNTY

Beaver Creek; secs. 30 and 32, T.47N., R.83W.; Manganese is exposed in isolated outcrops in a one-half by one-mile area trending north-northwest. The principal occurrence lies in the Flathead Formation (Cambrian). Here in the NW/4 sec. 32, weathered blocks of manganese-impregnated sandstone cover an east-west trending ridge about 150 feet above the Precambrian-Cambrian contact. Bulldozer trenches exposed a 25-foot-thick lense of manganese that parallels bedding. Overlying the Flathead occurrence is a clay bed (possibly the White River Formation) that contains some nodular manganese. Assays of the manganese-impregnated sandstone average about 9% manganese oxide (Osterwald and others, 1966, p. 130).

The second major occurrence crops out in the N/2 sec. 30. In this occurrence manganese occurs as pyrolusite nodules in White River Formation clays, and as pyrolusite stringers in Precambrian granite. A representative sample of nodular ore assayed 33.8% manganese oxide (Wilson, 1952).

Hose (1955, p. 88) also collected a sample of nodular pyrolusite from brown clays in the White River Formation. The nodular ore, which was retained on a ten-mesh screen, assayed 50.2% manganese oxide. Reserves of 300,000 to 1,000,000 tons containing as much as 60% manganese oxide have been estimated for the Beaver Creek group (Osterwald and others, 1966, p. 130).

Powder River mine; SE/4 NW/4 sec. 30, T.47N., R.85W.; Manganese is associated with auriferous quartz veins in amphibolite schist country rock (Hagner, 1942b).

Taylor prospect; sec. 19, T.47N., R.85W.; Located near the Powder River mine. Manganese fills fractures and stains surfaces of rock of the Bighorn Dolomite. Hagner (1942a) was of the opinion that this deposit was too irregular and too limited in size for commercial endeavors. A hand-picked high grade sample assayed 45% manganese and 15 oz/ton silver (Hagner, 1942a).

NATRONA COUNTY

Arminto manganese; Black wad (manganite) is reported in a 2.5 mile long, by 25 feet wide, by 45 feet deep deposit at Arminto (Osterwald and others, 1966, p. 131).

Koch manganese prospect; NE/4 sec. 30, T.32N., R.79W.; Pyrolusite replaces limestone and limestone breccia of the Casper Formation along the south side of Casper Mountain. The mineralization is irregular and occurs in patches and pockets (Hagner, 1942c).

WASHAKIE COUNTY

Gheen Nos. 1 and 2 claim; Located in the northeast corner of Washakie County, however no legal description was given. Pyrolusite, psilomelane, and braunite are associated with quartz and silicified limestone. Analysis of the mineralized rock produced the following results (Schack and Poole, 1947):

Mn	Fe	SiO_2
13.8%	1.9%	68.9%

WESTON COUNTY

Coates manganese; Lot 4, sec. 10, T.45N., R.60W.; Located near the top of a timbered plateau that overlooks the Stockade Beaver Creek valley. A short 45-foot adit penetrates manganese-bearing, yellowish-gray, thin- to massive-bedded Pahasapa(?) Limestone (Mississippian). Locally, these rocks strike N85°W and dip 11°N.

The manganese is localized in a four-foot-thick zone that parallels the strike and dip of bedding planes in the limestone. It is found as wad manganese filling cavities, as pods and lenses of silicified manganese, and as coatings on calcite. The deposit is reported to assay as high as 50% manganese (Wilson, 1957).

Platinum Group

The platinum group metals are platinum, palladium, iridium, osmium, rhodium, and ruthenium. Platinum and palladium are the more common of the platinum group, but the native metals are never chemically pure and contain various traces of the other platinum group metals in solid solution. The platinoids also often have traces of gold, silver, copper, iron, chromium, and nickel.

Platinum and palladium are used in jewelry, electrical equipment, catalytic converters, automobiles, many types of laboratory equipment, dental and surgical instruments, and in photography.

The platinum group metals are considered to be critical strategic metals because the United States has only 1.3 percent of the reserve base of the world, while South Africa and the Soviet Union control greater than 90 percent of the reserve base. The majority of our Nation's imports are supplied by the Republic of South Africa, United Kingdom, and the Soviet Union (Loebenstein, 1985).

The world's greatest primary platinum deposits are associated with the Bushvelt complex of South Africa (see CHROMIUM) and the Sudbury district of Ontario (see COBALT). Significant platinum also occurs in the Stillwater layered mafic complex in Montana and in some podiform ultramafic deposits (see CHROMIUM). In the layered complexes, platinum occurs as liquation grains near the base of the complex.

The platinum group metals have been found in Wyoming as silver-white, malleable nuggets and flakes, and as sperrylite in some of the copper ores at the New Rambler mine in the Medicine Bow Mountains. Sperrylite is an arsenide of platinum ($PtAs_2$). In Wyoming, the platinoids are principally found in sheared and hydrothermally altered mafic and ultramafic rock along the northern edge of the Mullen Creek mafic complex, in altered and sheared mafic rock along Centennial Ridge, and in placers derived from these areas in the Medicine Bow Mountains. Platinum nuggets occasionally occur in the Douglas Creek placers (Beeler, 1906a).

The New Rambler mine along the northern edge of the Mullen Creek mafic complex produced some platinum and palladium. In 1902, $6,000 was paid for platinum recovered from copper ore produced from the New Rambler mine. Some platinum production was also reported between 1915 and 1920.

The known platinum occurrences in Wyoming appear to be restricted to the New Rambler - Centennial Ridge area, but the extent of mineralization may not be thoroughly realized. It is important to note that the New Rambler deposits are found in intensely altered rock along the northern edge of the Mullen Creek mafic complex. There is a possibility that this deposit was remobilized from a more extensive platinum reef in the mafic complex.

ALBANY COUNTY

New Rambler district; The New Rambler district (often referred to as the Holmes district) is located north of the Keystone and Douglas Creek districts. For simplicity, these three districts are separated as such: (1) the Keystone district is defined as those base and precious metal deposits occurring in tensional fractures that are related to the Keystone quartz diorite, (2) the Douglas Creek district includes placer gold and platinum group metals in Douglas Creek and its tributaries, and (3) the New Rambler (Holmes) district includes base and precious metal deposits of mafic affinity developed within the Mullen Creek-Nash Fork shear zone.

The geology of the New Rambler district is typified by the New Rambler mine. This mine was developed in sheared amphibolitized rock along the northern edge of the Mullen Creek mafic complex, a layered tholeiitic mafic body. Base metals, gold, and platinum group metals occur in hydrothermally altered shears. Production in the district was essentially limited to the New Rambler mine.

Blanch mine; SE/4 sec. 32, T.15N., R.79W.; The Blanch mine is situated immediately west of the New Rambler workings within the New Rambler district. Shafts were sunk in sheared felsic gneiss, metagabbro, and metadiorite in an effort to locate an extension of the New Rambler ore body (McCallum and Orback, 1968). The main shaft was sunk to a depth of 160 feet, and at 120 feet penetrated a zone containing copper carbonates, chalcocite, and chalcopyrite (Beeler, 1902; 1906a). The copper minerals occur in quartz veins with pyrite, hematite, and limonite, and in quartz associated with gouge and shear zones (McCallum and Orback, 1968).

Duchess mine; SW/4 sec. 32, T.15N., R.79W.; Located west of the Blanch mine. Several exploratory shafts were sunk in shear zone tectonites and strongly sheared metagabbro and metadiorite. Traces of copper with pyrite, hematite, and limonite in quartz are evident in many of the workings (McCallum and Orback, 1968).

Medicine Bow Mines Company; A 954-foot-long tunnel cut a number of ore zones that carried values in copper, cobalt, and gold (Beeler, 1906a, p. 45-47).

New Rambler mine; SW/4 sec. 33, T.15N., R.79W.; Located west of the Rob Roy Reservoir. The New Rambler mine sporadically operated from 1900 to 1918 producing about 6,500 tons of copper ore which carried values in platinum, palladium, gold, and silver. At least 4,000 tons of the total production ran 25 to 30% copper. It has been estimated that high-grade ore and concentrate averaged 2.41 oz/ton palladium and 0.12 oz/ton platinum for possible production of 16,870 oz of palladium and 910 oz of platinum (Silver Lake Resources, 1985).

The New Rambler mine was developed in amphibolitized rock which is part of a large layered tholeiitic mafic complex known as the Mullen Creek mafic complex (see CHROMIUM). The more abundant rock types in the mine area are metadiorite and metagabbro that grade downward at shallow depths into metapyroxenite and metaperidotite. Minor diabasic and granitic rocks also occur in the mine area (McCallum, and others, 1976).

Structurally, an intense regional shearing is responsible for the high permeability of the host rock and in turn for the emplacement of the ore body. Old mine reports indicate that the mine workings intersected four well-defined northwest-trending fault planes and these presumably were intersected by a broad east-west zone of shear tectonites (Kasteler and Frey, 1949; McCallum and others, 1976).

Two hydrothermal assemblages are recognized and are overprinted by supergene alteration. Propylitic alteration assemblages incompletely replaced hornblende, and calcic plagioclase and biotite were generally unaffected. The propylitic mineral assemblage includes chlorite, epidote, clinozoisite, albite, magnetite, and pyrite. Phyllic alteration resulted in the pervasive replacement of calcic plagioclase and albite, whereas the mafic minerals were only partially affected. Sericite and quartz dominate as replacement assemblages with lesser amounts of pyrite as disseminations, veinlets, and magnetite overgrowths (McCallum and others, 1976).

The New Rambler ore body is a classical supergene enriched deposit with an overlying porous, spongy, limonite and jaspilite gossan which caps a 75-foot oxidized zone. Oxidized zone ore minerals form an extremely diverse assemblage containing abundant malachite, and azurite with lesser amounts of cuprite, tenorite, chalcotrychite, and chalcopyrite. Dendrites and nuggets of native copper with atacamite, chalcanthite, tetrahedrite, and bornite are sparsely distributed. This oxidized assemblage grades downward from about 75 to 100 feet into the supergene enriched zone consisting of platinum-bearing covellite and chalcocite. Below 100 feet, the supergene minerals grade into the primary mineralized rock containing quartz-pyrite-chalcopyrite veins (McCallum and Orback, 1968).

In 1949, the U.S. Bureau of Mines sampled the mine tailings with five-foot channel samples and identified low grade platinum and copper (Table 1). Thompson and Theobald (1968) also sampled the mine tailings. Their results are presented in Table 2.

Table 1. Copper-platinum assays of five-foot mine dump channel samples, New Rambler mine (after Kasteler and Frey, 1949).

U.S. Bureau of Mines sample number	Copper (percent)	Platinum metals (oz/ton)
1	0.92	0.10
2	1.22	0.02
3	0.15	trace
4	0.18	trace
5	0.67	trace
6	0.12	trace
7	0.24	trace
8	0.15	trace
9	0.09	none
10	0.08	trace
11	0.10	trace
12	0.05	none
13	0.31	0.01
14	0.80	0.04
15	0.81	0.02
16	0.85	0.05
17	0.75	0.04
18	0.47	trace
19	0.47	0.01
20	0.37	trace
21	0.40	trace
22	0.54	0.02
23	0.24	trace

Table 2. Analyses of mine tailings from the New Rambler Mine (analyses reported in parts per million) (after Theobald and Thompson, 1968).

Sample Number	Copper	Silver	Platinum plus palladium	Gold 2-g sample	Gold 10-g sample	Arsenic	Tellurium	Molyb-denum	Lead	Zinc
Coarse mine tailings in main mine area										
651	2.000	7.8	3.5	<0.1	1.3	40	8	15	<25	25
652	1.200	55	3	.9	3.0	10	25	15	20	<25
654	>6.000	1.5	.1	.3	.4	60	1	< 5	25	50
655	2.000	1.0	.4	< .1	.2	30	2.5	< 5	<25	25
656	1.000	14	1.7	.9	2.5	30	2	10	<25	25
662	3.000	2.0	.5	.8	.5	40	20	< 5	<25	25
667	1.200	1.8	6	.7	.2	30	2.5	5	25	50
Coarse mine tailings in outlying piles and mines										
664	80	1.0	0.2	0.2	0.04	10	0.25	<5	25	25
649	>6.000	2.8	.4	.9	1.0	30	2.5	<5	<25	50
Mill site debris										
666	2.000	7.2	1.0	2.6	0.3	120	13	5	750	25
680	2.000	4.2	1.6	.1	.5	160	15	<5	25	25
Mill tailings										
668	2.000	4.5	2.5	0.3	0.9	80	13	10	<25	25
669	2.000	2.2	.3	1.6	.2	30	4	5	25	25
670	1.000	2.8	1.0	.6	.3	60	7	5	<25	25
Outwash from mill tailings										
675	2.000	1.8	0.8	0.8	0.3	40	7	<5	<25	50
678	1.000	.5	.4	.5	.02	10	.1	<5	<25	25
Slag										
679	>6.000	3.8	0.7	1.5	0.08	<10	1.3	5	<25	75
Average	3.000	7	1.1	.8	.7	--	--	--	--	--
Outwash from mill tailings on Bear Creek flood plain										
737	600	0.8	0.6	0.3	0.06	20	0.5	<5	<25	50
738	2.000	4.8	2.0	.1	1.0	80	7	5	<25	50

Other assays of New Rambler ores reported in the literature include (1) composite samples of dump material that assayed 0.06 oz/ton platinum, 0.04 oz/ton iridium, 0.04 oz/ton palladium, 0.10 oz/ton silver, and a trace of gold, (2) various copper minerals from the mine contained from 0.10 to 0.70 oz/ton platinum, and (3) seven carloads of covellite ore contained from 0.40 to 1.40 oz/ton platinum (Knight, 1902).

Douglas Creek district; The Douglas Creek district was established after 1868 following the discovery of placer gold in Moores Gulch, a tributary of Douglas Creek. During the first year of heavy prospecting (1869), about 425 ounces of gold were extracted from placers in the district. Many of the washings were reported to have yielded 0.10 to 0.13 oz of gold to the pan. The gold varied from flour to coarse gold with flat nuggets. Some recent nuggets taken from Douglas Creek have been as large as 1/4 to 1/2 inch in length (Eugene F. Clark, personal communication, 1981). Beeler (1906a) reported the largest nugget found prior to 1906 weighed 68 pennyweights (3.4 ounces).

The auriferous gravels range from 3 to 20 feet thick and average five feet thick. Gold occurs sparsely throughout the gravels, but is concentrated on bedrock. In addition to gold, some platinum has been recovered from the Douglas Creek placers, particularly from the northern portion of the district.

The coarseness of the gold suggested that it was derived from a nearby source. This led to prospecting upslope from the drainages and to the discovery of a few gold- and platinum-bearing lodes. Total production from the Douglas Creek placers was estimated by Knight (1893) to be 2,100 oz of gold. Production figures after 1893 are not available. For additional information, refer to Hausel (1980).

Centennial Ridge district; In the Centennial Ridge district, two types of primary ore deposits have been recognized. Primary gold deposits occur in quartz veins which parallel foliation and schistosity of amphibolite- and mica-gneisses and schists of McCallum's (1968) Mafic Series unit. The primary gold deposits have been the most productive in the district and were developed at the Free Gold, Utopia, and Centennial mines. Primary gold-platinum deposits occur in shear zones, faults, and quartz veins where they cut Mafic Series units. The precious metals are associated with sulfides and arsenides which occur as fracture and breccia fillings (McCallum, 1968).

Centennial mine; SE/4 sec. 4, T.15N., R.78W.; The Centennial mine lies along the eastern flank of Centennial Ridge overlooking the town of Centennial. Production records indicate at least 4,800 ounces of gold were recovered from this mine in the late 1860s. The ore averaged 1.5 oz/ton gold.

The ore is free-milling and occurs in quartz veins and iron-stained shears in mafic amphibolitic schist and gneiss (McCallum, 1968). The principal vein followed a N45°E trend. Mining operations terminated after the vein abruptly ended against a fault (Hausel, 1980).

Cliff mine; S/2 SW/4 sec. 8, T.15N., R.78W.; The Cliff mine was developed by a 775-foot tunnel driven parallel to regional foliation. Near the end of the main tunnel, a 325-foot crosscut ran east-west and intersected four quartz and sulfide-bearing fractures. The first mineralized zone was intersected a few feet from the main drift and this vein carried about 0.6 oz/ton gold. The number three vein, located 140 feet from the main drift, carried some platinum values (Hess, 1926). The wallrocks are mafic schists and submylonites (McCallum, 1968).

Columbine mine; SW/4 sec. 17, T.15N., R.78W., The mine was developed on a N45°E shear in biotite, hornblende schist. Some copper values were reported, but otherwise no precious metals were noted (McCallum, 1968).

Empire mine; NE/4 NW/4 sec. 17, T.15N., R.78W.; Two adits were driven on iron- and copper-carbonate stained shears in mafic schist and gneiss country rock. The shears parallel regional foliation (McCallum, 1968). Assays of iron-stained, sulfide-bearing fractures ranged from a trace to 0.99 oz/ton silver, a trace to 0.06 oz/ton gold, a trace to 1.04 oz/ton platinum, a trace to 63.72 oz/ton (?) palladium, and a trace to 2.84 oz/ton iridium (Hess, 1926).

Fall Creek placers; sec. 7, T.15N., R.78W.; McCallum (1968) reported trace amounts of platinum and gold occurred in these placers.

Free Gold claims; SE/4 sec. 8, T.15N., R.78W.; Situated near the top of Centennial Ridge. The Free Gold claims were developed by a 30-foot exploratory shaft and nearly 800 feet of trenches on a 2 1/2-foot wide quartz vein. This vein was reported to carry free gold associated with oxidized pyrite and limonite boxworks. The host rock for the vein is hornblende and chlorite schist. The vein follows regional foliation. No platinum values were reported.

Four samples were collected for assay at the Free Gold shaft. A surface sample of vein material assayed 1.84 oz/ton gold; at 15 feet depth, the vein assayed 1.06 oz/ton gold; at 20 feet depth, the vein ran 0.52 oz/ton gold; and at 30 feet depth, the vein yielded 0.62 oz/ton gold per ton. Northwest of this discovery shaft, within 500 feet, a 10-foot-deep trench was dug on the vein. Assays of eight samples collected from the quartz vein ranged from 0.08 to 2.84 oz/ton gold, and averaged 0.89 oz/ton gold. Samples were also taken from the hornblende schist vein (shear zone ?) in contact with the quartz vein. Six samples collected from the schist ranged from 0.10 to 0.46 oz/ton gold and averaged 0.22 oz/ton gold. A single sample of quartz vein collected from an open cut west of the Free Gold shaft assayed 2.54 oz/ton gold (Dart, 1930).

Gold Crown Mining Syndicate; N/2 sec. 9, T.15N., R.78W.; Located on the slope of Centennial Ridge a few hundred feet south of the Utopia mine and on a northeasterly trend with the Free Gold claims. In 1930, the Golden Crown Mining Syndicate proposed developing an exploratory adit to intersect the Free Gold Claims exploratory workings from the eastern slope of Centennial Ridge. This property is apparently located on the eastern extent of the Free Gold vein. The vein, here, was reported to contain free gold in honeycombed quartz hosted by amphibolite schist. Six samples collected for assay along the line of the first 300 feet of the proposed tunnel assayed as followed (Dart, 1930):

Sample description	Gold (oz/ton)	Platinum (oz/ton)
Crown tunnel entrance face	0.52	0.72
Ledge outcrop, 50 feet from entrance	0.32	none
Old tunnel, 150 feet west of tunnel entrance	0.40	0.84
Ledge outcrop, 250 feet on strike above tunnel entrance	0.24	none
Red quartz and schist, 10-foot shaft on strike 300 feet above tunnel entrance	0.56	none
Altered rock, same location as above	trace	0.40

Gold Eagle claim; W/2 W/2 sec. 9, T.15N., R.78W.; Approximately 900 feet east of the Free Gold claims discovery shaft and a little more than 100 feet north of the Free Gold - Golden Crown mineralized trend. Two samples collected from the Golden Eagle discovery shaft assayed 0.72 and 2.49 oz/ton gold, respectively, and a third sample collected at the shaft's base assayed 3.12 oz/ton gold and 0.20 oz/ton silver (Dart, 1930). No platinum values were reported.

Independence mine; sec. 8, T.15N., R.78W.; Located along the west bank of the Middle Fork. The Independence mine was developed on a N35°W trend into sheared amphibolite schist and intersected five separate shears within 80 feet of the portal. At 30 feet into the adit, a crosscut followed a N68°E trending shear for 110 feet to the southwest. The shears are permeable as evidenced by persistent water flow through these fractures in the late spring and early summer. The nonsheared fine-grained biotite-amphibolite schist is competent impermeable rock (Hausel and Jones, 1982). Reported assays by McCallum (1968) suggest that the Independence is a low-grade gold-platinum resource, however, chip and channel samples collected by Hausel and Jones (1982) produced no detectable platinum or silver (Hausel, 1983). Bill K. Rogers (personal communication, 1983) recovered one sample of massive arsenopyrite above the adit that assayed 0.5 oz/ton platinum.

Kentucky Derby prospect; sec. 8, T.15N., R.78W.; On the east side of the Middle Fork of the Little Laramie River. The Kentucky Derby workings penetrate intensely shattered and sulfide-stained shear zone tectonites. The mineralized zone is oxidized and the sulfide masses are coated with films of limonite and alum. According to private communications to McCallum (1968), platinum group metals and gold were found on this prospect, however McCallum (1968) reported that his grab samples showed only traces of copper, gold, and silver and no platinum. One sample assayed by Theobald and Thompson (1968) ran 0.1 oz/ton platinum.

Middle Fork placers; W/2 sec. 17 and S/2 sec. 8, T.15N., R.78W. Gold and platinum occur in stream sediments along the Middle Fork of the Little Laramie River. Two of the best prospects include flat areas in sections 8 and 17 that have flood plain gravels and terrace deposits. The west side of the stream in the northern flat was reported to carry considerable gold although recent work did not substantiate this (McCallum, 1968). Much of the gold and platinum has worked its way to bedrock, which is a few or more feet deep.

Mother Lode prospect; sec. 1, T.15N., R.79W.; This prospect was developed by a small pit in alluvial and eluvial sulfide-stained boulders on the Middle Fork of the Little Laramie River. The mineralized rock occurs as pyritized quartz and pyritized amphibolite forming alluvial boulders and recent stream bank deposits. The pyritized rock extends several hundred feet upslope from the prospect pit. A selected sample of pyritized amphibolite was assayed and yielded no detectable gold or platinum (Hausel, 1982). Theobald and Thompson (1968) assayed one sample for platinum which produced <0.04 oz/ton.

Platinum City mine; NW/4 NE/4 sec. 16, T.15N., R.78W.; The Platinum City mine was developed in pegmatite, quartz, and sulfide veins and mylonite in amphibolitized metaigneous rock. The quartz veins carried some free gold, and the sulfide veins and pods commonly carried gold and platinum values (McCallum, 1968).

Queen Mill Run placer; NE/4 sec. 8, T.15N., R.78W.; Some gold and platinum were reported in alluvium at this locality (McCallum, 1968).

Queen shaft; NW/4 sec. 16, T.15N., R.78W.; The Queen shaft was developed into fault gouge in amphibolitized metapyroxenite. The exposed rocks in the shaft are cut by numerous small faults and veins of calcite and pegmatite. The faults commonly contain up to an inch of gouge, some of which is rich in sulfides (McCallum, 1968). Some gouge material collected by Hess (1926) assayed 0.03 oz/ton platinum, 0.05 oz/ton iridium, and less than one oz/ton silver with a trace of gold. Dump samples assayed in 1961 contained some copper (McCallum, 1968).

Utopia mine; N/2 NE/4 sec. 9, S/2 SE/4 sec. 4, T.15N., R.78W.; This property was developed by three separate adits in the early 1900s. Gold is associated with quartz veins, shear zones, and garnet inclusions in hornblende schist country rock (Dart, 1929). The mineralized veins were offset by faulting which resulted in the termination of mine operations (Hess, 1929). Assays were reported to range from a trace to 3.46 oz/ton gold, and a trace to 1.64 oz/ton silver (Dart, 1929).

Vivian claim; sec. 9, T.15N., R.78W.; Located south of the Utopia mine. One sample of schist from this claim assayed 0.46 oz/ton gold (Dart, 1930).

Woodman claim; sec. 9(?), T.15N., R.78W.; Located adjacent to the Free Gold claim. A sample of schist collected from the discovery hole assayed 0.94 oz/ton gold (Dart, 1930).

Wyoming Gold and Platinum Mining Company; at Centennial. The U.S. Bureau of Mines assays showed 11 oz/ton palladium with traces of nickel. The ore occurs in small cross-fractures that cut the mafic metamorphic rocks at right angles to foliation (Osterwald and others, 1966, p. 151).

CARBON COUNTY

Broadway mine; Located in S/2 SW/4 sec. 32, T.13N., R.83W. The Broadway mine consists of an irregular mineralized body lying along a northeast-trending contact between granite and a series of gneisses and amphibolites. According to Osterwald (1947), the metals probably replaced amphibolite along a 50- by 1,000-foot zone. The mineralized body dips 50°SE to 50°NW.

Mineralization includes sphalerite, galena, chalcopyrite, chalcocite, and covellite, with some malachite and chrysocolla near the surface. One channel sample assayed 12.5 percent zinc, 1.9 percent lead, and 0.02 percent copper with a trace of platinum group metals (Osterwald, 1947).

LARAMIE COUNTY

Silver Crown district; Aughey (1886, p. 54) reported palladium in the gold and silver ores of the district.

LINCOLN COUNTY

Snake River placers; Some platinum has been reported in the Snake River placers of Lincoln and Teton Counties. An assay of concentrate showed 4.54 oz/ton platinum from the Bailey Creek mining camp (Schultz, 1907, p. 87; Schultz, 1914, p. 126-130).

Conclusions

In summary, Wyoming has numerous scattered occurrences of critical strategic metals including a variety of other strategic minerals and metals. Unfortunately, very little information is available for many of these deposits, but similarities in the geologic settings of some of these deposits with world-class deposits suggests more detailed investigations are appropriate.

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