THE GEOLOGICAL SURVEY OF WYOMING
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By
W. Dan Hausel and Ray E. Harris

ABSTRACT

The State of Wyoming has several metallic deposits that are of potential commercial interest. Although all of these deposits have been prospected in the past, recent reinterpretations of tectonic settings have again made some of these deposits attractive exploration targets.

Some Precambrian deposits of interest include iron formations and lode gold found in metasedimentary and metaigneous rocks in Archean greenstone belts in central Wyoming; paleo-placer accumulations of uranium, thorium, and possibly gold in Early Proterozoic metaconglomerates occurring in continental margin miogeosynclinal successions; copper-zinc-gold mineralization hosted by Early to Middle Proterozoic calc-alkaline volcanogenic schists deposited in an island arc tectonic environment; and copper-gold-platinum occurrences in Middle Proterozoic shear zone tectonites in the southeastern portion of the state.

Phanerozoic metallic deposits that have received increased attention during the past decade include copper-zinc-silver deposits hosted by Pennsylvanian to Cretaceous red bed arenites in the Thrust Belt region of western Wyoming; Tertiary porphyry copper-molybdenum calc-alkaline stocks intruded into the Absaroka volcanic plateau of northwestern Wyoming; base-precious and rare earth metallic deposits hosted by Tertiary alkalic and peralkaline intrusives in the Black Hills uplift of northeastern Wyoming.

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INTRODUCTION

In Wyoming, significant mineral deposits occur in Precambrian supracrustals, in Paleozoic and Mesozoic miogeoclinal sediments, as well as Tertiary volcanics and intrusives. Based on age, the Precambrian basement within the State of Wyoming is separable into the: Archean (>2.5 b.y.) and the Proterozoic (<1.9 b.y.) provinces. The older Archean basement consists of relatively unmineralized gneisses, migmatites, granitic plutons and batholiths with isolated greenstone belts and greenstone belt fragments. These belts host a number of important mineral and ore deposits, in particular lode gold and banded iron formations.

Along the southeastern edge of this Archean craton are marginally situated Late Archean to Early Proterozoic basins filled with thick piles of miogeoclinal metasediments. Several fluvial units of the metasediments are radioactive and represent paleo-placer accumulations of uranium and thorium, and are possible targets for paleo-placer gold accumulations.

The older Archean basement abruptly terminates in southeastern Wyoming, against a younger Proterozoic basement (<1.9 b.y.) which is predominantly formed of volcanogenic schists and metasediments intruded by granitic plutons and batholiths (1.8 to 1.4 b.y.). Of interest are potentially commercial volcanogenic massive sulfides associated with the Proterozoic basement.

These two provinces are separated by the Mullen Creek-Nash Fork shear zone, the cataclastics of which are exposed in the Sierra Madre, Medicine Bow Mountains and Richeau Hills. Scattered base and precious metal deposits are found in shear zone cataclastics in both the Sierra Madre and Medicine Bow Mountains.

Much younger (Paleozoic-Mesozoic) copper-silver mineralization is localized in near shore to shoreline nonmarine red bed arenates in the Overthrust Belt of western Wyoming and southeastern Idaho. These host sandstones were deposited along the eastern edge of a miogeoclinal basin during the Late Paleozoic to Late Mesozoic. The mineralization is epigenetic and stratabound.

More recently, the eruption of tremendous volumes of calc-alkaline magmas formed an extensive volcanic plateau in northwestern Wyoming during the Early Tertiary. The centers of volcanism lie along a northwesterly trend, and field relations suggest structural control. Later erosion has dissected the plateau, known as the Absarokas, and exposed several mineralized porphyry stocks located at the former sites of the eruptive centers.

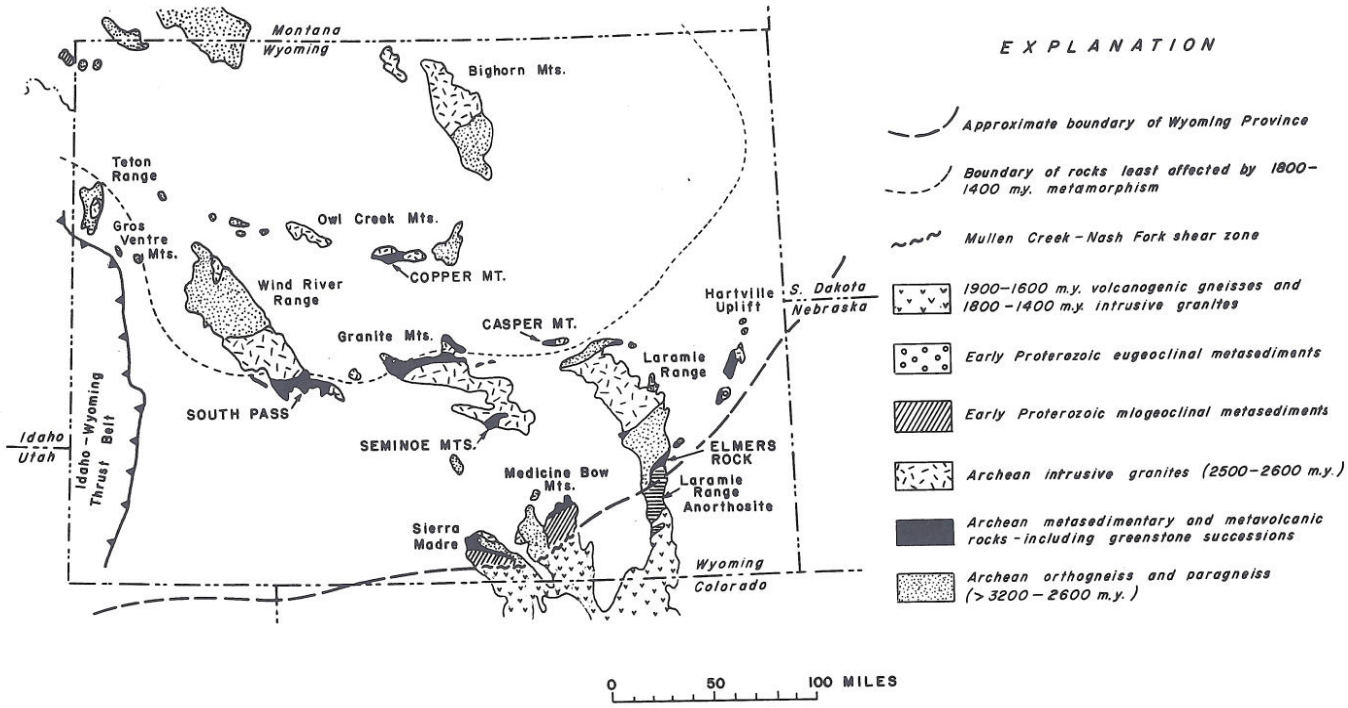

FIGURE 1. Generalized basement map of Wyoming (after Condie, 1976; Houston and Karlstrom, 1979; and Karlstrom and others, 1981).

Base metal, thorium, uranium, and rare earth deposits in the Black Hills area are closely associated with Tertiary alkalic intrusives. These deposits are believed to be the result of magmatic differentiation.

GREENSTONE BELTS AND ASSOCIATED GOLD AND IRON

Geology

Partial to near complete exposures of greenstone belts are interspersed and form deep basinal areas within the Archean gneissic terrain (Figure 1). These belts consist of supracrustal metavolcanic and metasedimentary rocks interpreted to lie on a gneissic basement. Some of the oldest, well-preserved igneous and sedimentary rocks on the North American continent are found in these steeply dipping basins. These supracrustals are assumed to be Archean (Condie, 1976; Houston and Karlstrom, 1979).

The South Pass greenstone belt, located near the southern tip of the Wind River Range, is one of the more thoroughly examined belts in the state, because of its commercial taconite and historic gold production (Figure 1).

This greenstone belt was intruded along its northwestern margin by the Louis Lake Batholith at about 2.7 b.y. (Bayley and others, 1973). In that the supracrustal rocks of the belt are cut by the 2.7 b.y. old batholith, a 2.7 b.y. or greater age is assigned to this greenstone belt. The remaining greenstone terrains in the state are probably of similar age to the South Pass region.

Some features characteristic of Archean greenstone belts, worldwide, are listed in Table I. In general, these belts form linear steeply dipping basins that stratigraphically have a lower ultramafic-mafic volcanic sequence that grades upward into a more felsic bimodal calc-alkaline sequence. Overlying the volcanic successions is a sedimentary group dominated by chemical precipitates.

Many features found in greenstone belts worldwide have been observed in the Wyoming belts (Table I). At the Seminoe Mountain belt, a fairly well-preserved ultramafic-mafic volcanic section is exposed near the mouth of Sunday Morning Creek on the northern flank of the range (Figure 1). Klein (1981) described 10 separate serpentinized basaltic-, peridotitic- and pyroxenitic-komatiite flow units at this locality.

At the base of the flows are cumulates that grade upward into aphanitic to fine-grained metavolcanics. The tops of the flows are coarse-grained radiating to parallel spinifex komatiites with thin layers of highly foliated monomineralic tremolite-actinolite rock (recrystallized glass?). Many of

TABLE I. Some characteristics recognized in greenstone belts worldwide (modified from Graff and others, 1982).

Structural	Stratigraphic	Miscellaneous	Mineral Deposits
Bordering granite-gneiss domes	Rapid facies changes	Greenschist to amphibolitic grade metamorphism	Nickel sulfides associated with high-magnesium ultramafic magmatic segregates (dunites and peridotites with more than 36% MgO).
Post metamorphic granites	Dominant basal mafic to ultramafic unit with komatiitic compositions	Mafic and ultramafic dikes in bordering gneisses	Asbestos and talc found as hydrothermal alteration products of mafic and ultramafic volcanics.
Keel-shaped synclinal folds	Pillow lavas	Mafic schlieren in bordering gneisses	Chromite deposits found in stratiform ultramafic intrusives.
Curvilinear axial traces	Basal mafic-ultramafic section grades upward into bimodal, dominantly felsic metavolcanics	Metamorphic grade higher at edges than in center of belt	Gold occurs principally in fissure-filled quartz lodes and less commonly in iron formations.
Highly strained boundaries with granitic gneiss	Lower dominantly volcanic sequence overlain by dominantly metasedimentary unit with chemical and clastic sediments	Elongated, narrow synformal basins	Stratiform Cu-Zn deposits generally associated with calc-alkaline mafic to felsic volcanics.
Steep regional dip		Flanks invaded by a series of late tectonic diapiric plutons	Iron ore and manganese in metasedimentary sequences.
Schistosity parallel to bedding			Lithium, tantalum, beryllium, tin, molybdenum, and bismuth associated with granites and pegmatites.
Branching synclines			
Strike faults along synclines			

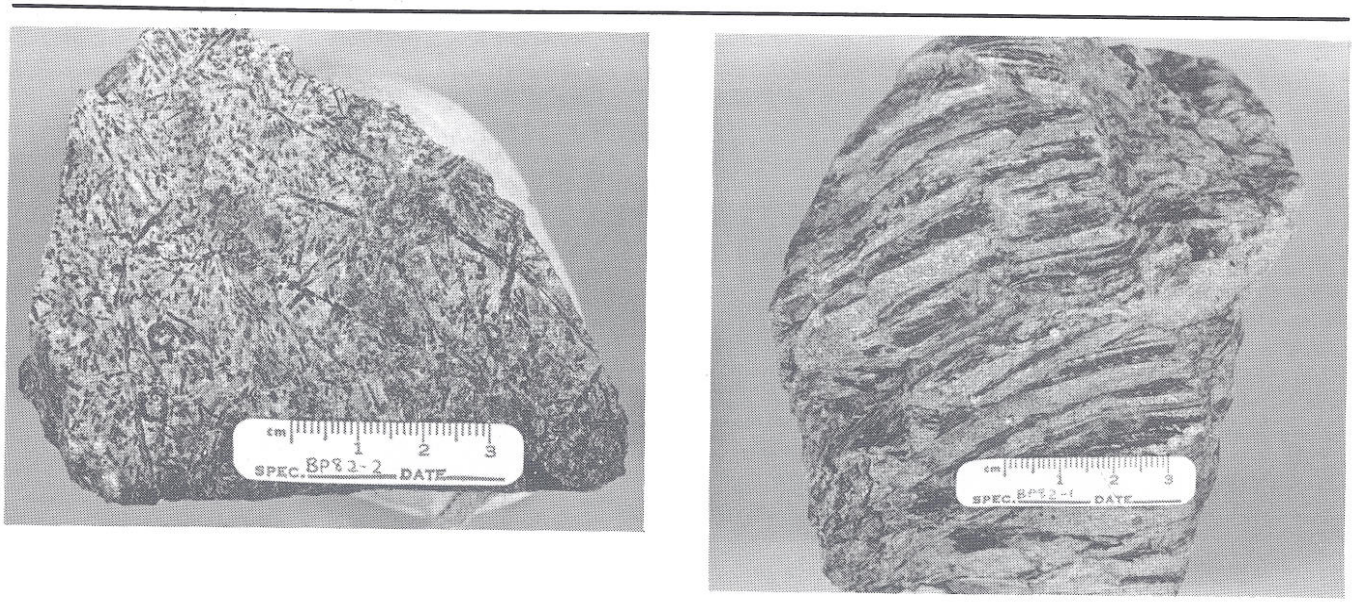

FIGURE 2. a) Radiating spinifex komatiite and b) parallel spinifex komatiite from Seminoe Mountains.

the flows are separated by thin banded iron formations. The textures exhibited by each flow are indicative of crystallization of a supercooled liquid which resulted in the spinifex textures (at the top of the flows) with fractionation and crystal settling to form the cumulus textures in the slower cooling base (Klein, 1981).

Graff and others (1982) recognized komatiitic tremolite-actinolite schists forming a portion of the lower ultramafic-mafic sequence in the Elmers Rock greenstone belt (Figure 1). These are magnesium-rich metamorphics with similar chemistry to reported komatiites elsewhere, although the characteristic spinifex texture is lacking. Pillow basalts have been identified in both the Elmers Rock (Graff and others, 1982) and South Pass greenstones (Bayley and others, 1973), as well as in some similar metavolcanic terrains.

Bimodal calc-alkaline metavolcanic flows have been described by Klein (1981) in the Seminoe Mountains, at Elmers Rock (Graff and others, 1982), and at South Pass (Bayley and others, 1973). These generally are andesitic to dacitic in composition, and account for only a small volume of the supracrustals.

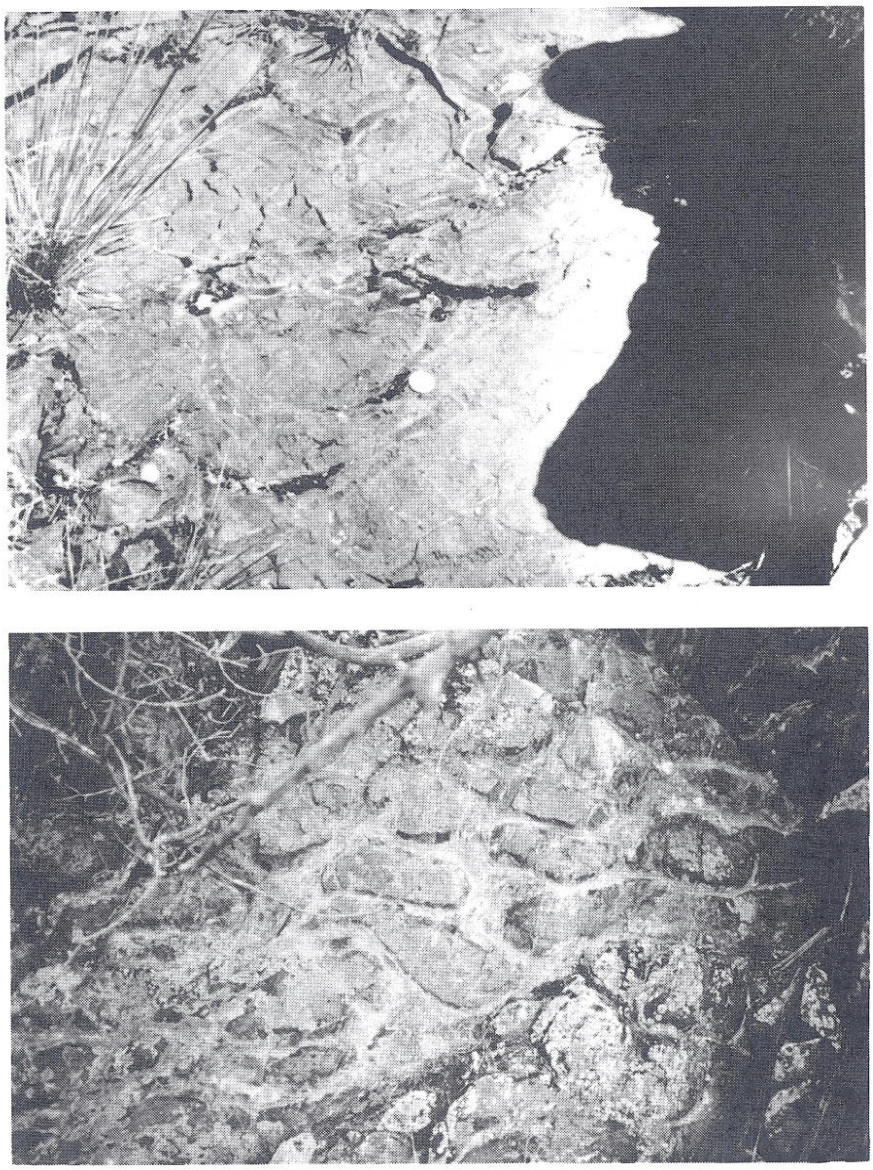

FIGURE 3. Pillow textures from a) the Elmers Rock greenstone belt, and b) the Hartville Uplift

The metasedimentary succession in the Seminoes is formed of thick iron formations overlain by metagraywackes, pelitic schist, graphitic schist, quartzite, and metaconglomerates. Metasediments at South Pass are dominated by a thick metagraywacke section with lesser pelitic schist, metaconglomerates, quartzite, and iron formation (Bayley and others, 1973).

These Wyoming greenstone belts are linear and synformal with steep regional dips. The margins of the belts, typically, have been invaded by late intruding granitic plutons. At South Pass, the Louis Lake Batholith, a post-tectonic granitic pluton, has numerous mafic inclusions along its contact with the greenstone belt. These fragments are interpreted as fragmented pieces of the basal unit, or units, of the greenstone belt that were incorporated into the pluton upon intrusion (Bayley and others, 1973).

These belts are also intruded by small gabbroic bodies. These mafic intrusives and bordering granitic plutons are important to the genesis of fracture-filled gold lodes.

Mineralization

Greenstone belts typically have characteristic types of mineral and ore deposits (Table I). Some general overviews of greenstone belt mineralization are published in Windley (1977) and Watson (1976). Wyoming greenstone belt reviews are available in Hausel (1982a) and Graff and others (1982).

To date, only two types of significant mineral and ore deposits reportedly occur in Wyoming greenstone belts. These are banded iron formations (oxide facies) and lode gold.

Significant tonnages of iron formation occur at South Pass and at the Seminoe Mountains. At South Pass, the banded silica-magnetite-grunerite-garnet iron formation has been structurally thickened, making it feasible for open pit mining (Bayley and others, 1973). More than 90 million tons have been extracted by U.S. Steel Corporation at their Atlantic City Mine since the initiation of operations in 1962. Gold has not been reported in these taconites and selected samples have assayed only a trace, to no gold.

Harrer (1966) estimated that the Seminoe Mountains host 50 to 100 million tons of iron ore resources contained in banded iron formations. Some gold is apparently localized in these metasediments (Lovering, 1929, p. 230; Hausel, 1982a) although the extent of mineralization may be restricted. Two samples of altered iron formation near the Penn Mines on Bradley Peak (sec. 6, T.25N., R.85W) contained interesting amounts of gold (Table II); however, samples collected elsewhere by Lovering (1929) and by more recent exploration groups have reported only traces to no gold.

Although Fripp (1976) reports significant stratabound gold deposits in iron formations in Zimbabwe, it is speculated that this may not be the case for the Bradley Peak mineralization. The association of the auriferous rock with epigenetic alteration suggests that the gold is localized and may have been introduced during the same hydrothermal episode responsible for the auriferous quartz veins in the adjacent Penn mining area. These auriferous quartz veins contain some associated copper sulfides, pyrite and minor sphalerite. The veins are small and range from small subparallel quartz stringers to 3-feet-thick N.20°E. trending veins.

Epigenetic alteration which accompanies veining occurs as silicification, carbonatization, and chloritization (Klein, 1981). Silicification extends several feet from quartz veins into the adjacent metagabbro country rock and is manifested by a distinct bleaching of the wall rock. Carbonatization is more widespread and often is recognized by massive carbonate replacements accompanied by fine-grained chlorite. Similar secondary carbonate was found in one of the iron formation samples which assayed better than 1.0 ounce per ton gold (Table II).

The major recognized gold deposits in the South Pass belt occur as fracture-fill auriferous quartz veins. The veins trend northeast and are developed in structurally competent metagabbro and less competent schist and metagraywacke of the Miners Delight Formation. For the most part, the veins are conformable to bedding and folding in the schist (Bayley and others, 1973). Ore shoots are commonly localized at vein intersections, or near the crests of anticlinal folds (Armstrong, 1947).

Later faulting acted as conduits for late stage quartz mineralization. These late stage veins contain some copper and gold, but generally have proven to be of little economic interest (Bayley and others, 1973; Hausel, 1980a).

TABLE II. Assays of selected samples from the Bradley Peak area, Seminoe Mountains (after Hausel, 1981).

Sample No.	Sample Location	Gold oz/ton	Sample Description
5081	E½ E½ Sec. 6, T.25N., R.85W	2.87	Selected quartz vein sample from mine dump
6761	NE¼ SW¼ Sec. 6, T.25N., R.85W.	1.137	Selected Iron Fm. (?)-Altered metagabbro(?) containing disseminated sulfides
6762	Center Sec. 6, T.25N., R.85W.	1.363	Selected silicified and carbonated iron formation

Genesis

The auriferous quartz veins at South Pass and the Seminoe Mountains have many differences which probably are the result of different modes of genesis. At South Pass, Bayley and others (1973) assume that the close spatial relationship of the veins to the metagabbro is structural rather than genetic. The metagabbro, being fairly competent, was fractured during folding of the greenstone belt. The fractures were filled with siliceous solutions provided by a granitic magma.

A late intruding granitic magma, such as the Louis Lake Batholith, provided the hydrothermal ore solutions. Major elements (Si, Fe, and K) and minor elements (Au, As, Ag, Bi, B, Cu, and Mo) were probably introduced by the granite. The mafic minor elements (Co, Cr, Ni, Sc, and V) detected in the quartz veins were undoubtedly leached from the gabbro by the hot circulating granitic hydrothermal solutions and incorporated into the quartz veins (Bayley and others, 1973). Alteration associated with the veins includes restricted sericitization of feldspars in wall rock to complete replacement of feldspars by microcline.

At Bradley Peak, the auriferous quartz veins are associated with extensive silicification of the wall rocks accompanied by carbonitization and chloritization. Analyses of the quartz veins and wall rock suggest that the vein-forming material was mobilized from the wall rock during a thermal event and transported to the dilational zones (Klein, 1981).

Many of the important gold deposits in greenstone belts worldwide are believed to have a similar genesis. The major auriferous quartz veins are located in fracture systems adjacent to granitic intrusives along the greenstone belt margins. The tenor of the lodes tends to decrease with greater distance from the plutons, suggesting a genetic relationship (Windley, 1977).

Not much information is available on the genesis of the iron formations in the Wyoming belts. Only oxide facies deposits have been described. In the Seminoe Mountains, iron formations occur as relatively thin units in the volcanic sequence and also in the sedimentary sequence. Windley (1977) proposed that many of these Archean iron formations found throughout the world are chemical sediments derived from an exhalative process and deposited under relatively low oxidizing potentials. The oxide facies are characteristically deposited in shallow waters along a shelf margin (James, 1954).

Other types of deposits that are commonly associated with greenstone belts such as chromite, nickel sulfides, asbestos, stratiform copper, and industrial minerals have not been reported in significant amounts in the state, although some asbestos was extracted from the Casper Mountain greenstone terrain during the 1800's (Hausel and Glass, 1980).

URANIFEROUS CONGLOMERATES

The southeastern edge of the Wyoming province is overlain by thick piles of Late Archean and Early Proterozoic low-grade metasediments (Figure 1). These supracrustals were deposited in epicontinental and miogeoclinal basins along the southeastern margin of the Archean craton. The metasediments lie nonconformably on Archean granite and gneiss that is dated at about 2.5 b.y. (Karlstrom and Houston, 1979).

Three successions of metasediments have been mapped in the northern Sierra Madre and Medicine Bow Mountains by Graff (1978) and Karlstrom (1981). The lower succession, termed the Phantom Lake Metamorphic Suite, is metamorphosed to amphibolite grade. Metavolcanics, quartzites, minor phyllites and marbles dominate the succession. The lower portion of the suite contains some weakly radioactive beds of conglomerate, paraconglomerate and micaceous quartz, and the upper portion has a fluvial micaceous quartzite with some mildly radioactive conglomeratic channels that lie unconformably on the lower unit (Button and Adams, 1981).

The Deep Lake Group unconformably overlies the Phantom Lake Metamorphic Suite. The Deep Lake Group is dominated by quartzites and conglomerates and is relatively unmetamorphosed. In both the Sierra Madre and Medicine Bows, the succession has been subdivided into six formations.

The Magnolia Formation, which is the basal formation of the Deep Lake Group, is of particular interest. In the Medicine Bow Mountains, the Magnolia Formation consists of a lower conglomeratic member which grades upward into finer grained clastic sequences. The conglomeratic member is an arkosic quartzite with channels of conglomerate that are relatively radioactive. The clasts are well-rounded and consist of quartzite, phyllite, metavolcanics and granite pebbles in a pyrite-arkosic matrix. The clasts are similar to the quartzite and phyllites found in the lower Phantom Lake Suite. In some areas, the basal conglomerate member of the Magnolia Formation is absent, yet in other localities, such as in the Dexter Peak area of the Sierra Madre, the conglomerate is composed mainly of quartz vein clasts in a pyritic, sericitic matrix. The radioactive conglomerates are apparently derived from a nearby source and deposited unconformably on metabasalts of the upper Phantom Lake Suite (Karlstrom and Houston, 1979). The remainder of the Magnolia Formation consists of a fining upward quartzite sequence that is prominently trough crossbedded (Button and Adams, 1981).

Mineralization

From an exploration standpoint quartz pebble conglomerates are not only a source of uranium, but also a source of gold. Similar metaconglomerates are mined for uranium in Blind River, Canada, and for gold and uranium in the Witwatersrand of South Africa.

As much as 0.14 percent uranium (anonymous, 1981) and 10 ppm gold (Paul Graff, pers. comm., 1981) have been reported in association with the Wyoming metaconglomerates. Pyrite grains generally comprise a few tenths to as much as 10 percent of the conglomerates (Karlstrom and others, 1981). Radioactive heavy minerals are coffinite, thorite, thorogummite, monazite, huttonite (?), and zircon.

These uranium and thorium minerals are in masses that may have been rounded originally, but now appear recrystallized with irregular borders or overgrowths (Karlstrom and others, 1981).

Genesis

These metaconglomerates in these miogeoclinal successions represent fluvial sediments that were deposited in southwesterly flowing streams and river systems during the Late Archean to Early Proterozoic. The heavy minerals in the metaconglomerates were concentrated by stream action and are believed to represent fossil placer deposits (Houston and Karlstrom, 1979; Karlstrom and others, 1981; Harris and Hausel, in prep.). Another possible mode of genesis for these Wyoming deposits that has been applied to the Witwatersrand, South African auriferous and uraniferous metaconglomerates is a hydrothermal origin (Stanton, 1972, p. 573). Evidence of a hydrothermal genesis is lacking, and the bulk of the evidence supports placer deposition.

The presence of coffinite and pyrite as detrital grains in the conglomerate matrix suggest that the conditions of transportation involved relatively low oxidation potential. In the present oxidizing atmosphere, pyrite and coffinite at normal pH would be unstable in a fluvial environment, and would quickly oxidize. Thus, in order to transport and concentrate uranium and pyrite in stream placers at atmospheric conditions, the Archean to Early Proterozoic atmosphere must have been relatively reducing and oxygen poor. In support of this conjecture, paleo-uranium and pyritic placers are unknown after the Early Proterozoic (2.0 b.y.), which is when the earth's atmosphere is assumed to have evolved to a more oxidizing medium. Banded iron formations which are believed deposited in a reducing atmosphere are also rare after the Early Proterozoic.

It is apparent that paleo-placer uranium formation is limited by the development of an oxidizing atmosphere at about 2.0 b.y. Unlike uranium and pyrite, this change in the atmosphere had little to no effect on gold, in that native gold is stable over a wide range of oxygen potentials.

The development of commercial uranium and gold placers, however, is limited at greater ages. The source rock of much of the uranium and thorium found in these paleoplacers is inferred to be late intruding "pink" (potassium-rich) granites which intruded the Archean craton between 2.45 and 2.6 b.y. (Peterman and Hildreth, 1978). These granites contain above-average radioactivity and are relatively more enriched in uranium and thorium than the depleted granite-gneiss basement which they intrude. The most favorable gold source for the placer would be metaigneous suites of the greenstone belts. These belts formed possibly between 2.5 and 2.7 b.y. ago. Based on these facts, the best paleo-placer targets would be limited to 2.0 to 2.6 b.y. old metaconglomerates for uranium, and fluvial deposits no older than about 2.7 b.y. for gold.

The better metaconglomerate exploration targets would lie immediately above an unconformity, and would have a demonstrated sourced area in the vicinity of a potassium-rich Archean granite (for uranium) or a greenstone belt (for gold).

The mean direction of paleocurrent data measured on fluvial sediments in the Phantom Lake Metamorphic Suite and the Deep Lake Group indicates that their source area is located to the northeast (Karlstrom and Houston, 1979). In this direction, Precambrian rocks are exposed in the Laramie Range. These exposures consist of Archean gneiss, potassium-rich granite and older metasedimentary rocks which include quartzites, chert beds, and some greenstone segments. The general lack of historic gold mines in the Laramie Range region suggests that gold in these fossil placers is probably limited.

The better uraniferous conglomerates should also occur in the Magnolia Formation. The radioactive fluvial sediments in the Phantom Lake Metamorphic Suite are not considered as good exploration targets because of age constraints. These are Late Archean and probably formed prior to the emplacement of K-rich granites. The relative amount of radioactivity for these Phantom Lake fluvial deposits is considerably less than that of the basal conglomerate member of the Magnolia Formation which would be expected because of the age constraints (Houston and Karlstrom, 1979; Karlstrom and others, 1981).

MASSIVE SULFIDES

South of the Mullen Creek-Nash Fork shear zone in the southern Sierra Madres, Medicine Bows, and Laramie Range is a series of amphibolite metamorphic grade eugeoclinal Middle Proterozoic (1.9 to 1.6 b.y.) metamorphics (Figure 1). These regions were intruded by granitic plutons (1.8 to 1.4 b.y.) which disrupted and fragmented the Proterozoic basement. Some of the better preserved metavolcanic rocks are found in the Sierra Madres and grouped into the Green Mountain Formation (Divis, 1976; 1977). The metamorphics of the Green Mountain Formation are interpreted to have been deposited in an island arc to back arc tectonic setting, and were later accreted to the Archean craton at about 1.7 b.y. ago (Hills and Armstrong, 1974).

Geology

The Green Mountain Formation forms a series of calc-alkaline metavolcanics and volcaniclastics with mafic to felsic compositions. Relic volcanogenic textures, such as vesicular, agglomeratic, and porphyritic are recognizable at some localities (Divis, 1977).

Lindgren (1908), Osterwald and others (1966) and Spencer (1904) have reported a number of mineralized deposits in this region that generally contain either pyrrhotite-chalcopyrite, pyrite-chalcopyrite, or galena-sphalerite-pyrite with varying amounts of gold and localized lead, zinc, nickel, cobalt, and traces of platinum. In general, these deposits have been classified as (1) disseminated mineralization in hornblende schist, (2) tactite-like garnet epidote streaks, (3) bedding replacement bodies in quartzite layers, (4) hornblendic contact metamorphic zones bordering diorite-gabbro intrusives, and (5) quartz veins and pegmatites.

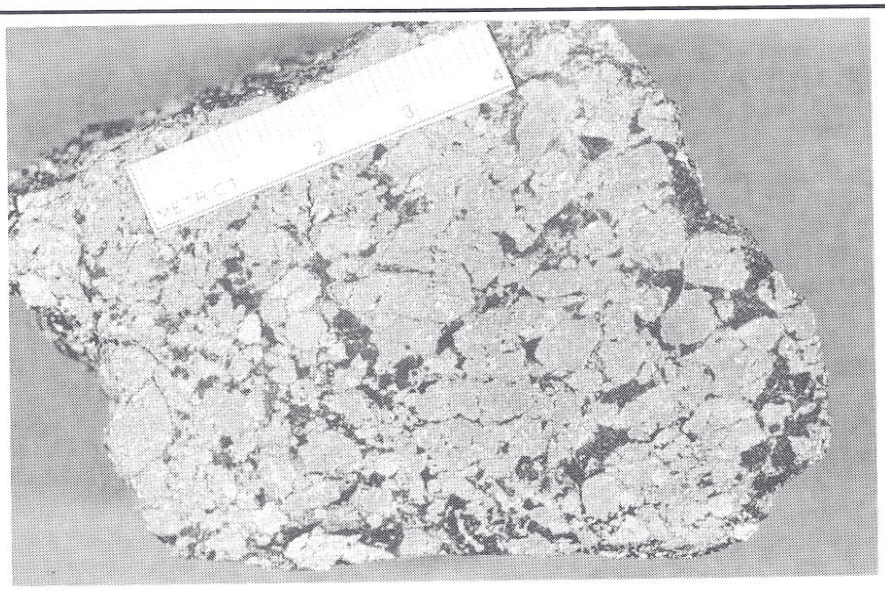

FIGURE 4. Massive pyritized colloform ore from the Itmay mine. The pyrite is mantled by chalcopyrite.

With further exploration, some of these deposits will undoubtedly be reclassified as stratabound volcanogenic (Hausel, 1980a, p. 66; 1982a). The tectonic setting, along with a considerable volume of felsic metavolcanics, are favorable factors for the deposition of volcanogenic massive sulfides similar to the Kuroko type (i.e., see Franklin and others, 1981, p. 531-536).

Massive sulfides within the Huston-Fletcher Park area are spatially associated with metarhyolite and brecciated metavolcanics. The metarhyolites are pyritized and display good quartz eye textures. Metavolcanics at the Itmay Mine (sec. 14, T.13N., R.86W.) are intensely altered felsics (rhyolites? andesites?). The mineralization associated with the altered rock occurs as massive pyritized iron formation. Hand specimens of massive sulfides from the mine dump contain pyrite: the pyrite exhibits colloform texture mantled by chalcopyrite set in a matrix principally of magnetite with lesser quartz, chlorite, and muscovite (Figure 4). Pyritized iron formation (magnetite) is associated with the metavolcanics and presumably lies at the footwall of the Itmay Mine. Within a few hundred feet to the north of the Itmay shaft are recognizable volcanogenic breccias (mill rock) containing felsic fragments up to eight inches across in a chloritized matrix. Similar volcanogenic breccias have been used successfully as a guide to massive sulfides in Canada (Sangster, 1972). A reported assay by Osterwald and others (1966) of an ore specimen (obviously selected) from the Itmay Mine produced 17.92 percent copper and 0.05 ounces of gold per ton.

A second stratabound deposit reported by Swift (1982) is exposed at the old Hinton Mine (also called the Verde Mine) located in sec. 32, T.13N., R.85W. This deposit was reported by Osterwald and others (1966) as chalcopyrite-magnetite mineralized hornblende schist. A sample of analyzed ore from the shaft assayed 8.18 percent copper and 0.02 ounces per ton gold. More recently, Swift (1982) examined this property and reported that ore specimens contained varying amounts of chalcopyrite, pyrite, and minor magnetite in a fine-grained hedenbergite matrix. The ore is stratabound and lies adjacent to a fragmental unit and an iron oxide-garnet-epidote exhalite (Swift, 1982).

In the Silver Crown District, on the eastern flank of the Laramie Range, copper-gold deposits are localized in fault gouge and in quartz veins developed in metaigneous rock (Klein, 1974). For the most part, intermediate to felsic volcanic rocks are lacking in this region, and the deposits are more characteristic of epigenetic hydrothermal deposits. Mineralization at the Copper King Mine in the southern portion of the district is disseminated in granodiorite and quartz monzonite, and also occurs in small scattered rehealed quartz veins and veinlets and as fracture fillings in cataclastics and mylonites in the immediate area. The host granodiorite exhibits medium-grained, porphyritic to foliated textures while the quartz monzonite has medium-grained to aplitic textures. Hydrothermal alteration is expressed as a broad zone of propylitization with a more localized zone of apparent potassic alteration (the Geological Survey of Wyoming is presently conducting both microscopic and x-ray diffraction research to better define the alteration zones). The potassic altered zone was mapped based on increased amounts of pink potassium feldspar, biotite, and muscovite in hand specimen (Hausel and Jones, 1982). The propylitic zone was defined on the appearance of increased amounts of epidote, chlorite, and sulfides. Drilling has substantiated low-grade reserves of 35 million tons of 0.21 percent copper with 0.02 ounces per ton of gold (Nevin, 1973).

Genesis

Many of the sulfide deposits in the southern Sierra Madre and Laramie Range are volcanogenic. Some of these deposits in the Sierra Madre are characteristic of proximal or of distal volcanogenic massive sulfides, and others are more characteristic of epigenetic hydrothermal deposits possibly related to felsic intrusives. The association of the Hinton ores in the Sierra Madre with fragmental rocks, and the association of the Itmay ores also with fragmental "mill rock" is evidence for proximal deposition. This "mill rock," or fragmental tuff breccia, generally underlies, or lies adjacent to, ore deposits, and is considered to have formed from magmatic explosions followed by repeated steam explosions as the hot felsic magma erupted from an undersea volcanic orifice and contacted cool seawater (Hughes, 1982, p. 50). The sulfides associated with the breccias represent products of differentiation from the magmatic melts erupted from the volcanic orifice (Evans, 1980).

The relationship of these deposits with felsic metavolcanics suggests some similarities to the Japanese Kuroko deposits (Sato, 1977). Although Hutchinson (1980) notes that Kuroko ores contain lead and a more complicated ore mineralogy than has been reported from the Hinton and Itmay ores, more diversified ore mineralogies have been reported from some nearby properties in the Sierra Madre (i.e., see Osterwald and others, 1966). For example, within two miles to the west of the Itmay Mine on the eastern boundary of sec. 16, T.13N., R.86W., a mineralized outcrop is stained with tenorite, malachite, and spotty marmatite, suggesting a more diversified mineralogy in this nearby area. However, the lack of fragmental rocks near this copper-zinc deposit would suggest that it is more characteristic of distal deposition rather than proximal as at the Itmay.

The Silver Crown ores are epigenetic hydrothermal. Each deposit exhibits some form of hydrothermal alteration, and the mineralizing event probably occurred during the last stages of the emplacement of the Sherman Granite Batholith or later. The Sherman Granite was emplaced at about 1.4 b.y. (Ferris and Krueger, 1964).

The Sherman Granite at the Rambler Group in the Curt Gowdy State Park on the western edge of the district is hydrothermally altered to propylitic assemblages (Hausel and Jones, 1982). The granite also contains copper-zinc mineralization associated with the hydrothermal alteration. These field relationships are evidence that the mineralization at the Rambler Group, and possibly in the entire Silver Crown District, is later than the Sherman Granite Batholith. The hydrothermal solutions which localized these deposits probably were related to a felsic intrusive event.

SHEAR ZONE

The Mullen Creek-Nash Fork shear zone represents a boundary between the Archean basement (to the north) and the Proterozoic basement (to the south) (Figure 1). The shear is interpreted as a fossil platetectonic boundary where the primitive oceanic crust collided with the Archean craton. The shear zone is as much as 4 miles wide and consists largely of cataclastics (Houston and others, 1968). The shear zone cataclastics contains scattered mineral deposits.

Geology

Several mines were developed in sheared cataclastics along the Mullen Creek-Nash Fork shear zone during the late 1800's (Curry, 1965; McCallum, 1968; McCallum and Orback, 1968; Hausel, 1980a, b; Hausel and Jones, 1982), principally for gold, copper, and platinum mineralization.

One of the better mineral properties was the New Rambler Mine (sec. 33, T.15N., R.79W.) in the New Rambler District. This property was operated periodically from the late 1800's until 1918 when much of the property suffered extensive damage from a fire. Six thousand, five hundred tons of ore, yielding copper, gold, silver, platinum, and palladium were recovered (Kasteler and Frey, 1949).

The mine was developed in sheared amphibolitized rock located along the northern edge of the Mullen Creek mafic complex which is a large layered tholeiitic mafic body. The more abundant rock type in the area is medium- to coarse-grained metadiorite and metagabbro that grades downward into metapyroxenite and metaperidotite (McCallum and others, 1976).

An intense regional shearing is reponsible for the high permeability of the host rock and for the formation of the important supergene enriched ores that were extracted during the lifetime of the mine. An east-west branch of the Mullen Creek-Nash Fork shear zone intersects a northwest trending shear at the mine site (McCallum and Orback, 1968, plate 1).

In addition to supergene alteration which produced some high-grade copper ore, two hydrothermal alteration assemblages are recognized. Propylitic alteration incompletely replaced hornblende and calcic plagioclase, while biotite, generally, was unaffected. The propylitic alteration products include chlorite, epidote, clinozoisite, albite, magnetite, and pyrite. Phyllic alteration pervasively replaced both calcic plagioclase and albite, whereas the mafic minerals were only weakly affected. Sericite and quartz dominate as replacements in the phyllic altered zone with lesser amounts of pyrite occurring as disseminations, veinlets, and as magnetite overgrowth (McCallum and others, 1976).

In the Centennial Ridge District, two types of primary ores have been recognized. Primary gold deposits occur in quartz veins which parallel foliation and schistosity of amphibole-mica schists and gneisses of the Mafic Series rocks. Primary gold-platinum deposits occur in shear zones, faults, and quartz veins where they cut the Mafic Series rock units. The precious metals are associated with fracture and breccia filling sulfides and arsenides; these deposits are spotty, and are apparently of limited extent.

Genesis

McCallum and others (1976) suggest two possible origins for the shear zone metalliferous deposits. Because the

metals at the New Rambler are associated with hydrothermal alteration products, an epigenetic hydrothermal origin is apparent. In one case, the metals which were probably derived from hydrothermal leaching of the host mafic rock were deposited in permeable fractures in cataclastics and as replacements.

A second possible origin, but less likely, would derive the ores during magmatic segregation processes of the mafic complex and then tectonically translate the ores to their present location in the shear zone. Hydrothermal reworking by fluids would introduce the metals into permeable zones in the cataclastics (McCallum and others, 1976).

RED BED COPPER-SILVER

Setting

Several red bed sandstones of Late Paleozoic through Mesozoic age in western Wyoming and southeastern Idaho contain some interesting copper and copper, silver, and zinc mineralized zones. Very little is known or published about these deposits, even though they may represent attractive exploration targets.

The reported deposits are found in the Timothy Sandstone Member of the Thaynes Limestone (Lower Triassic), in arenaceous units of the Wells Formation (Pennsylvanian-Permian), in the Beckwith Formation (Jurassic-Cretaceous), and in the Nugget Sandstone (Triassic-Jurassic).

These sandstones were deposited as nonmarine red beds in near shore to shoreline settings along the eastern edge of the Rocky Mountain miogeosyncline. During the Early Cretaceous, this region was affected by intense tectonism which produced complex folding and faulting that continued well into the Tertiary, forming the Overthrust Belt. This region is a site of complex folds, thrust faulting and rapid facies changes.

Geology

Two of these mineralized areas were developed to the extent that ore was shipped. A small tonnage of copper was shipped from Montpelier, Idaho in the early 1900's (Mansfield, 1927, p. 346), and a slightly greater tonnage was shipped from the Griggs and Ferney Gulch properties in the Lake Alice District, Wyoming (Lloyd, 1970, pp. 131-134).

At Montpelier, Idaho (Figure 5) the copper deposits are found in the Timothy Sandstone Member of the Thaynes Limestone. The copper occurs as malachite and azurite stains on joint surfaces and along the bedding planes of massive calcareous sandstone and shaley units. At depth, in mine workings, several sulfide zones were intercepted. The recognized sulfides occur as chalcocite and covellite replacements of organic debris. The mineralization is stratabound although the mineralized zones are irregular and not confined to any particular bedding plane in the stratum.

Mansfield (1927, p. 346) reports that 70 tons of hand sorted ore containing 18 percent copper were shipped from the Bonneville claim (sec. 27, T.13S., R.45W.), located east of Montpelier. A representative sample of mineralized rock was reported to assay 2.85 percent copper (Gale, 1909).

Mineralized rock in the Lake Alice District of Wyoming (Figure 5) is hosted by the Nugget Sandstone. In this area, the Nugget Sandstone is an arenaceous unit and contains some gypsiferous siltstone, claystone, and minor carbonates. Large cross-stratified sandstone beds in the upper portion of the Nugget are similar to coastal dunes and large submarine sand waves (Kamis, 1977). Inland sebkhas were depositional sites for gypsum, gypsiferous siltstone and claystone. Carbonates were formed in small lakes between dune areas (Picard, 1977).

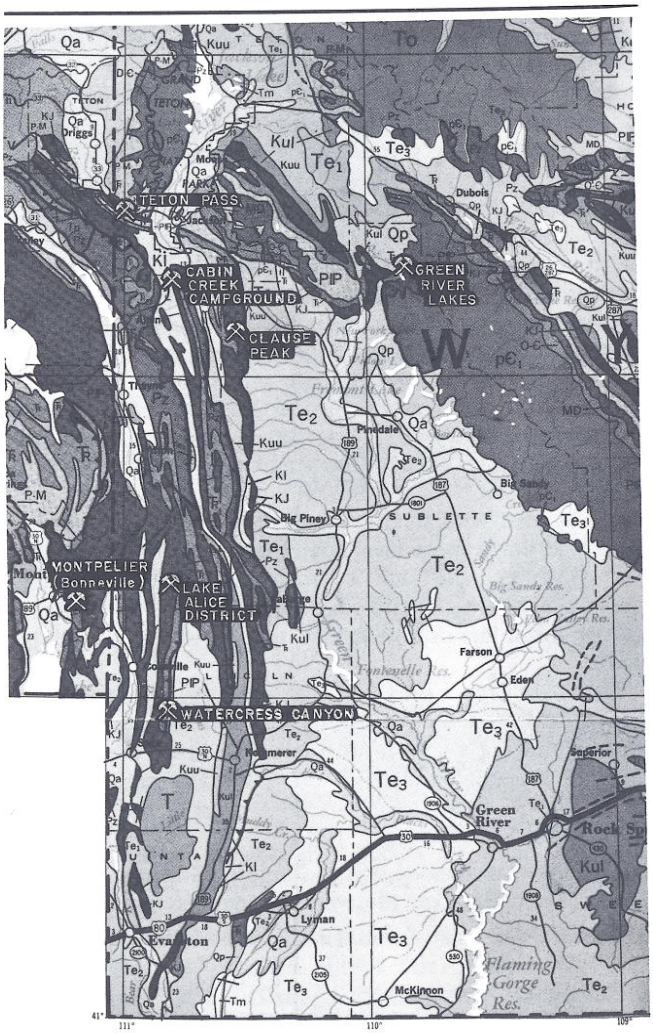

FIGURE 5. Location map of known mineralized sandstones in the Overthrust Belt. Base map-AAPG Geologic Highway Map no. 5.

In the Lake Alice District, the mineralized sandstone is localized at the top of the Nugget Sandstone where the hanging wall of the deposit is formed by the Gypsum Springs Member of the Twin Creek Limestone—the Gypsum Springs Member also contains some mineralization, (Boberg, 1983). Wherever the sandstone is mineralized, the host red bed has been bleached or altered white in contrast to the typical dull

hematite-stained unaltered rock (Love and Antweiler, 1973; Hausel, 1982a).

In this district, the Griggs Mine (sec. 7, T.28N., R.117W.) was developed by several adits using stull-type stoping. The adits extend over a vertical distance of 300 feet from the lowermost adit to the upper adit at the top of the Nugget. Identified ore minerals include malachite, azurite, tenorite, and chalcopyrite. Samples collected from the property assayed 180 ppm to 67,000 ppm (6.7%)* copper, a trace to 5,000 ppm lead, 26 ppm to 31,000 ppm zinc, and a trace to 1,200 ppm (36 ounces) silver (Love and Antweiler, 1973). Allen (1942) reported that average assays from one of the Griggs tunnels contained 3.5 percent copper and 7.4 ounces silver per ton.

Some ore was shipped from the Ferney Gulch Mine (sec. 1, T.27N., R.118W.), located six miles south of the Griggs Property. Mineralization at Ferney Gulch has all the same characteristics as the Griggs Mine, although this property does not appear to be as extensively mineralized. A selected sample reported by Love and Antweiler (1973) contained 50,000 ppm (5%) copper, 15 ppm silver, 26,000 ppm (2.6%) zinc, 700 ppm cobalt, 500 ppm lead, and 70 ppm molybdenum. A sample collected by the Geological Survey of Wyoming in 1982 contained 1.11 percent copper, 0.52 ounces per ton silver, 137 ppm zinc, and a trace (63 ppm) of cobalt.

At Spring Lake Creek (SE¼ sec. 24, T.28N., R.117½W.), a 110-foot adit was driven into altered Nugget Sandstone. Malachite and pyrite are visible, although sparse. Two samples collected from the walls of the adit contained 500 ppm and 2,100 ppm copper along with traces of silver and zinc (Love and Antweiler, 1973). A sample of selected dump material collected by the Geological Survey of Wyoming in 1982 contained 0.25 percent copper, 46 ppm zinc, and traces of silver.

Several additional localities have been reported (Table III).

Genesis

There are a few characteristics that are important to unraveling the genesis of the Nugget Sandstone deposits: (1) the mineralized portions occur where the red beds have been bleached white by the reduction of ferric iron; (2) without exception, mineralization occurs at the top of the Nugget along its contact with the overlying impermeable Gypsum Spring Member of the Twin Creek Limestone; (3) no organic material of any significance has been identified in the mineralized areas (unlike the Montpelier, Idaho deposits); and (4) at the Griggs Mine, the major mineralized sandstone occurs within fractured and sheared sandstone.

Love and Antweiler (1973) suggest that these mineralized zones in these red beds were derived from metal-bearing petroleums, even though no petroleum has been observed at the mineralized sites. It is suggested that metalliferous oil migrated into and through the permeable sandstone which was capped by the overlying impermeable gypsum beds. Bleaching, similar to that found in the mineralized Nugget, occurs in Triassic red beds in areas of oil saturation in central Wyoming (Love and others, 1945; Love, 1957), and ash in some of these hydrocarbons will often contain anomalous metal concentrations (Hyden, 1961).

The petroleum would not only provide a source of metals but also a reducing environment to bleach the red beds. Sulfur for the metallic sulfides could come from sulfate ions leached from the overlying gypsum beds. Sulfate bacteria feeding on the hydrocarbons would reduce the sulfate ions to sulfide ions, which would then combine with metals to precipitate the insoluble metallic sulfides (Love and Antweiler, 1973).

The possibility that the metals in the Nugget Formation were interformational, mobilized by compaction and diagenesis, and localized by rare organic debris or H_2S should also be considered.

Such a mode of genesis has been proposed for the Montpelier deposits. Although, unlike the Nugget mineralized zones, the Montpelier copper deposits are intimately associated with organic debris. These deposits may be the result of interformational mineralizing fluids set into motion by folding and by compaction. The mineralized fluids would migrate until the host metals were reduced. The organic debris found in the Timothy Sandstone would act as a reductant, and H_2S-producing bacteria could provide an excellent source of sulfur to precipitate metallic sulfides.

PORPHYRY COPPER-MOLYBDENUM DEPOSITS

Introduction

Several volcanic centers in the Absaroka Mountains of northwestern Wyoming exhibit disseminated, stockwork, and vein mineralization, and hydrothermal alteration, characteristic of many porphyry copper deposits of the Basin and Range physiographic province, southwestern U.S. For the most part, the Absaroka porphyry systems approximate the Lowell and Guilbert (1970) porphyry copper model, although similarities to the Diorite Model (Hollister, 1974; 1978) may also be present, but less common.

The mineralized centers (Figure 6) are characterized by a central intrusive complex. Adjacent to the intrusive complex are vent-facies autoclastic flow breccias, lava flows, mudflows, avalanche debris, and tuffs. The vent-facies rocks commonly are domed, altered, and radially fractured and, in the southern Absarokas, grade laterally into volcaniclastics. The appearance of these volcanic complexes is that of a dissected stratovolcano, or shield volcano.

Mineralization associated with these volcanic centers generally occurs as disseminations and stockworks in intensely altered rock, and in fractures and veins that transect both the mineralized intrusive and the vent-series wall rocks. The effect of hydrothermal alteration processes has been to produce zones of mineralization and alteration. Generally, copper, molybdenum, and trace gold occupy the

*To convert ppm (parts per million) to percent, multiply the ppm by 10^{-4}, such that 10,000 ppm x 10^{-4} = 1.0%.

TABLE III. Assays from mineralized red bed arenate samples collected in the Overthrust Belt of western Wyoming.

	Prospect	Location	Cu (percent)	Zn (ppm)	Pb (ppm)	Ag (ppm)	Co (ppm)	Reference	Formation
LAKE ALICE DISTRICT	Griggs Mine	7-28N-117W	0.02-6.7	26-31,000	tr.-5000	tr.-1200	tr.-20	Love & Antweiler, 1973	Nugget
	Ferney Gulch	1-27N-118W	5.0 1.11	26,000 100	500 ---	tr. 17	700 63	Love & Antweiler, 1973 Geol. Survey of Wyo. files, 1982	Nugget
	Spring Lake Creek	24-28N-117½W	0.21-0.5 0.25	tr. tr.	--- ---	tr. tr.	--- ---	Love & Antweiler, 1973 Geol. Survey of Wyo. files, 1982	Nugget
	Coantag	NE¼ 36-28N-117½W	0.39	32	---	2	---	Love & Antweiler, 1973	Nugget
	Landslide Dam	20-28N-117W	0.086	22	---	1	---	Love & Antweiler, 1973	Nugget
	Big Park	E½ 12-27N-117½W	*	---	---	---	---	Love & Antweiler, 1973	Nugget
CLAUSE PEAK	Cabin Creek	SW¼ 37N-114W near headwaters of Cabin Creek	*	---	---	---	---	Love & Antweiler, 1973	Nugget
	Halfturn Creek	NE¼ 37N-115W near headwaters of Halfturn Creek	3.0	---	70	150	---	Love & Antweiler, 1973	Nugget
	Green River Lakes (Mill Creek)	43° 19'/109° 51'	*	---	---	---	---	R.E. Harris, Geol. Survey of Wyo. files, 1983	Nugget
	Cabin Creek Campground	43° 15'/110° 47'	0.15	23	---	trace	---	Geol. Survey of Wyo. files, 1982	Nugget
			6.80	150	5600	0.9	30	R.E. Harris, Geol.Survey of Wyo. files, 1983	Nugget
	Watercress Canyon	NW¼ 4-22N-118W	0.1-7.5	70-360	30-700	0.6-2.7	---	Rubey and others, 1975	Wells
	Cockscomb	19N-120W	*	---	---	---	---	Osterwald and others, 1966	Beckwith
	Teton Pass	—	*	---	---	---	---	J.D. Love, pers. comm., 1982	Nugget

* sample stained with copper carbonates — no reported assays.

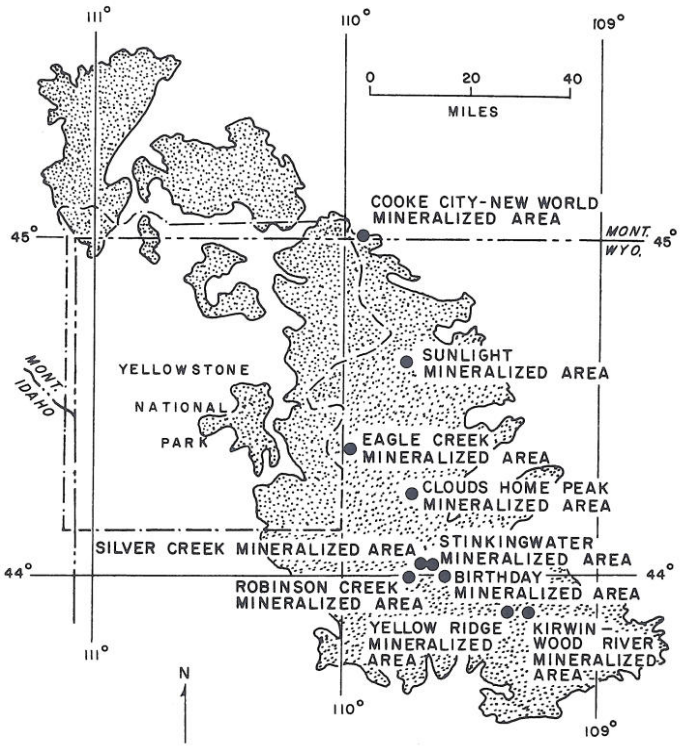

FIGURE 6. Location map of the known porphyry copper-molybdenum intrusive centers of the Absaroka plateau.

central portion of the complex. These metals give way to zinc, lead, and silver ores laterally away from the center of the intrusive complex. Both mineralized and barren intrusive centers are the source of the great pile of volcanic rock that forms the Absaroka Mountains.

The Absaroka volcanic field covers more than 8,000 square miles of surface area in northwestern Wyoming and southern Montana. The bulk of the field consists of calc-alkaline andesites with lesser basaltic and dacitic rock. These occur as flows, flow breccias, and breccias that grade into volcaniclastic sediment in the southern half of the field; the northern half of the field is predominately volcanic flows and related igneous rocks. A small volume of the Absaroka field (about 10%) is formed of potassic alkalic mafic flows of the shoshonite suite. The genesis of these ultra-potassic flows is discussed by Prostka (1973), and their genesis will not be elaborated here.

The tremendous volume of volcanic material (greater than 7,000 cubic miles) erupted from several volcanic centers that lie along a north-northwesterly trend. The locations of these centers are marked by intrusive stocks and plugs, with dikes and veins radiating outward from the central intrusive complex. These intrusive complexes contain stocks and plugs commonly of granodiorite, quartz monzonite, monzonite, diorite, syenogabbro, or syenite composition that exhibit equigranular to porphyritic texture. Peripheral to these intrusive complexes are volcanic flows, flow breccias, and breccias that in the southern Absarokas grade outward into well-bedded deposits of epiclastically reworked volcanic debris comprising well-sorted volcanic breccia, conglomerate, sandstone and tuff (Lipman and others, 1972). These volcaniclastics predominate in the southern Absaroka field (Wilson, 1971). The entire Absaroka Range has the appearance of a deeply dissected volcanic plateau, with the volcanics (Eocene-Oligocene?) unconformably overlying Paleozoic and, in places, Mesozoic sediments.

The Absaroka volcanics and volcaniclastics are termed the Absaroka Supergroup. Generally, the Absaroka Supergroup averages greater than 5,000 feet thick (Smedes and Prostka, 1972), and in places is as much as 6,000 feet thick (Wilson, 1964).

The Absaroka Supergroup is divided into three groups which are in turn subdivided into formations: from oldest to youngest, the groups are the Washburn, Sunlight and Thorofare Creek groups. The Washburn Group is restricted in the northern part of the field and represents the oldest volcanic rocks. It is unconformably overlapped in most places by the Sunlight and Thorofare Creek groups. Nearly everywhere, the Thorofare Creek Group overlies the Sunlight Group.

The Sunlight Group is the most mafic unit and contains the highest proportion of basaltic potassic rock. Most of the rocks of the other two groups are generally lighter colored and andesitic and dacitic in composition.

The Mineralized Centers

The mineral deposits in the Absarokas occur as: (1) disseminated and stockwork mineralization in intensely altered stocks and, at a few localities, in country rock adjacent to mineralized stocks; (2) fracture-filled veins and veinlets extending outward from the mineralized centers; (3) fracture- and fissure-filled veins and replacement deposits hosted by Paleozoic carbonates (recognized only in the New World District); (4) supergene enriched deposits; and (5) placer gold deposits down drainage from porphyry districts.

Mineralization of the stocks is associated with hydrothermal alteration of varying intensity. All of the districts exhibit widespread deuteric propylitic alteration. Near the intrusive centers, the deuteric alteration takes on the effects of hydrothermal propylitic alteration. Generally, the presence of veins or veinlets of calcite, epidote, chlorite and pyrite in the propylitically altered rock signifies that the deuterically altered rock has been overprinted by hyrothermal alteration.

Phyllic alteration (quartz-sericite-pyrite) is recognized near disseminated copper mineralization at all of the known mineralized areas except the Sunlight Basin, where this alteration halo is absent. Argillic alteration has been identi-

fied at several of the intrusive centers, although in most cases the described alteration is apparently supergene rather than hypogene alteration. Potassic alteration has been identified in several of the districts, although the potassic halo is generally poorly defined.

Porphyry Copper Models

Two porphyry copper models are generally recognized by most exploration geologists. These are the Lowell and Guilbert (1970) model, and the Diorite model (Hollister, 1974). Although the Lowell and Guilbert (1970) model is generally thought to characterize nearly all of the Absaroka porphyry deposits, few of these, other than possibly Kirwin, Stinkingwater, and Sunlight Basin have been studied in sufficient detail to assign a characteristic model with confidence. Both the Kirwin and Stinkingwater appear to more closely approximate the Lowell and Guilbert model, and the Sunlight Basin has some similarities to the Diorite porphyry model.

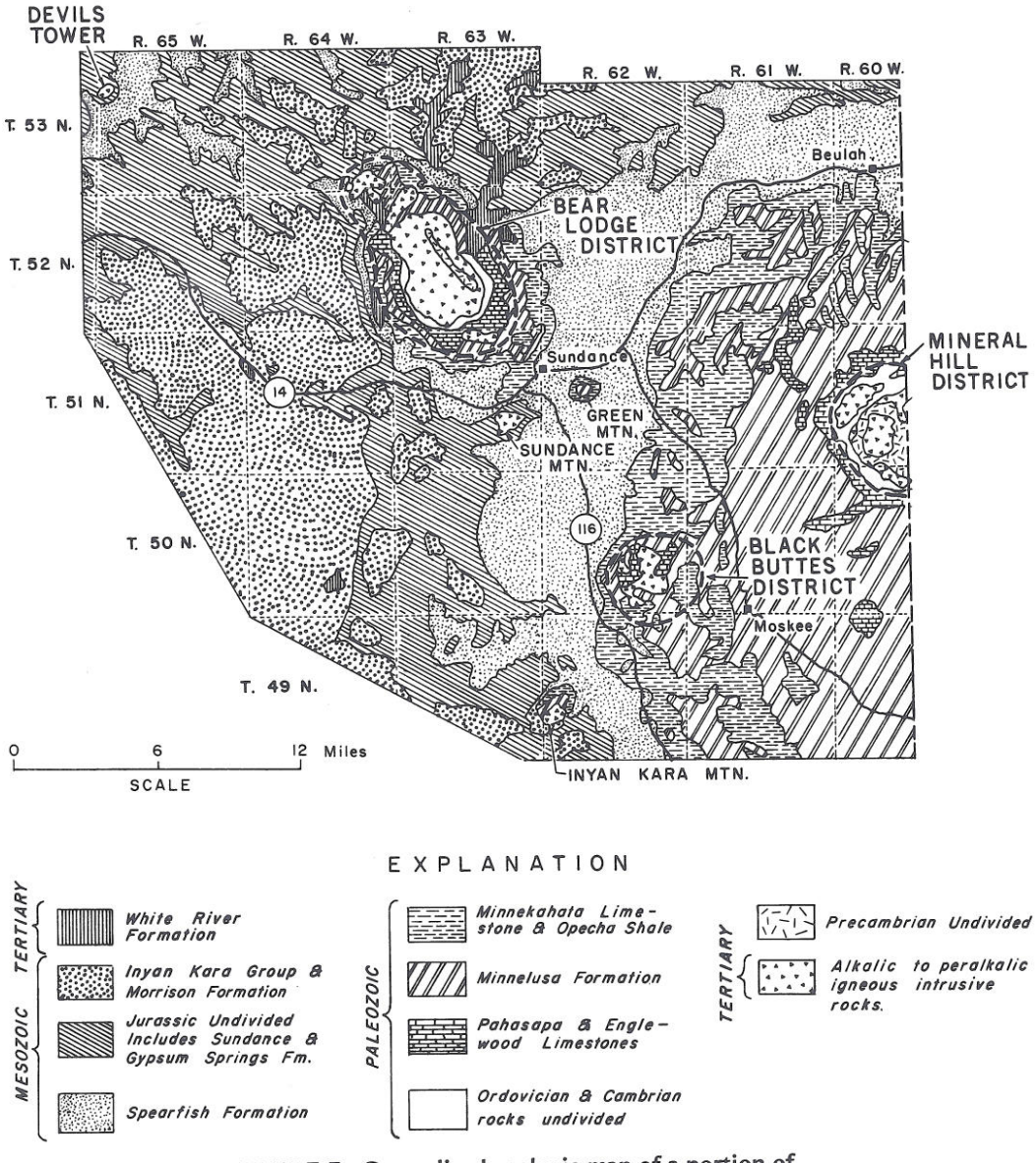

FIGURE 7. Generalized geologic map of a portion of the Black Hills uplift (after Love and others, 1955).

ALKALIC AND PERALKALINE TERTIARY INTRUSIVES AND ASSOCIATED METALS

Six separate alkalic to peralkaline intrusive centers are found in the Black Hills of northeastern Wyoming (Figure 7.) These are the Bear Lodge, Mineral Hill, Black Buttes, Devil's Tower-Missouri Buttes, Sundance Mountain-Green Mountain, and Inyan Kara Mountain intrusives. Of these, only the Bear Lodge and Mineral Hill intrusives are associated with potentially important mineral resources.

The Bear Lodge Intrusive complex consists of trachytes, phonolites, latites, and carbonatites (White, 1980; O'Toole, 1981; and Wilkinson, 1982), and the Mineral Hill intrusive is an alkalic ring dike complex composed of trachytes, pyroxenites, pseudoleucite porphyries, syenites, syenodiorites, lamprophyres, and diorites.

These rocks are alkaline to peralkaline with some calc-alkaline phases and represent a suite of unusual rocks undersaturated with respect to silica and alumina. Intrusive relationships and petrographic studies indicate that these rocks cooled at shallow depths and in different stages. No extrusive rocks are known.

Rocks of similar composition elsewhere contain important reserves of niobium, copper, rare earth elements, uranium, thorium, phosphorus, vermiculite, and fluorine, and occurrences of gold, molybdenum, and other precious metals. Notable examples are the copper deposits of Phalaborwa, South Africa; niobium at Araxa', Brazil, and Lueshe, Zaire; rare earths at Mountain Pass, California; uranium at Saima, China, and Pocos de Caldas, Brazil; vermiculite at Libby, Montana; and gold at Kirkland Lake, Ontario.

Mineralization

Rare earth elements, thorium, as well as other elements, have an affinity for alkalic and peralkaline magmas. Differentiation within the alkaline melt produces areas where these elements are concentrated, and late hydrothermal vapor phases further concentrate some of the elements.

The Bear Lodge Mountains intrusive has recently been prospected for uranium and rare earth minerals. Uranium occurs in values up to 2.0 percent eU_3O_8 at the Sunrise Lode (secs. 21 and 22, T.52N., R.63W.) and in amounts greater than 0.05 percent eU_3O_8 at other locations (Harris and Hausel, 1983). Prospecting for rare earth minerals and niobium has centered about the northern carbonatite. A previously unreported carbonatite has been mapped by Gordon Jenner, a graduate student at the University of North Dakota, near the southeastern margin of the pluton, and rock types in this area are favorable for rare earth minerals, fluorite, and niobium in pyrochlore.

The Bear Lodge Mountains intrusive may also contain important thorium resources. The U.S. Geological Survey has undertaken a study of this thorium occurrence, and preliminary work by Mortimer Staatz has been published (Staatz and others, 1979). Work by the U.S. Geological Survey has delineated an area containing thorium-rich manganiferous veins in the central part of the intrusive.

In addition, several fluorite occurrences are reported on the margins of the intrusive in recrystallized limestone (Osterwald and others, 1966). A copper occurrence similar in mineralogy to Phalaborwa copper deposits occurs near the northern carbonatite (Deans, 1966). A value of 10.1 ounces per ton gold was reported by Robert Jones (personal comm. to R. Harris, 1982) from a chip sample of altered trachyte from sec. 20, T.52N., R.62W. Previously, no gold anomalies had been reported from this area, and little serious prospecting has been done for gold.

The Mineral Hill alkalic complex contains numerous lode and placer prospects, and is currently receiving exploration for base and precious metal deposits. A group of chip samples collected in the Mineral Hill area assayed 20 ppm to 11,000 ppm copper, 2 to 5,700 ppm lead, none to 6 ppm gold, and none to 115 ppm of silver per ton (Welch, 1974). The highest assays were collected from a silicified feldspathic breccia in the S½ sec. 29, T.51N., R.60W.

Copper mineralization in the Black Buttes area, located to the west of Mineral Hill, is found as scattered, unpredictable pockets replacing limestone (Hausel, 1980a). Although some mineralization is found at Black Buttes, this area does not appear to have a great potential for producing strategic and other valuable minerals as does the Bear Lodge Mountains and Mineral Hill occurrences.

Genesis

These mineral occurrences are derived from magmatic differentiation separating silica-poor, alkalic magmas from normal alumina silicate magmas by differential melting at relatively low temperatures (Sorenson, 1974). Structural conditions favorable to the migration of these magmas are also necessary. These conditions are usually found in areas of active rifting, such as found at expanding geotectonic plate boundaries involving continental crust (Bailey, 1974). The African rift is an example where carbonatite lavas are being extruded from active volcanoes such as Oldoinyo Lengai in Tanzania. These plutons generally occur in linear belts, such as in Africa or in western Montana. A similar belt of Tertiary alkalic and calc-alkaline plutons occurs in the northern Black Hills, extending from the Missouri Buttes-Devil's Tower area eastward into South Dakota. The Bear Lodge Mountains intrusive is apparently the most highly differentiated and consequently the most alkaline pluton reported from this belt.

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