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INTRODUCTION

In Wyoming, significant mineral deposits occur in Precambrian supracrustals, in Paleozoic and Mesozoic micaceous 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 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 micaceous 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 volcanic-sedimentary schists and metasediments intruded by granitic plutons and batholiths (1.8 to 1.4 b.y.). Of interest are potentially commercial volcanic-sedimentary massive sulfides associated with the Proterozoic basement.

These two provinces are separated by the Mullen Creek-Nash Fork shear zone, the cataclasites 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 cataclasites 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 arenites in the Overthrust Belt of western Wyoming and southeastern Idaho. These host sandstones were deposited along the eastern edge of a micaceous 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.

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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 1. 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 1). 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
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**

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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, 1975). 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
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The metavolcanic succession in the Seminole is formed of thick iron formations overlain by metagraywackes, pelitic schists, graphitic schists, quartzites, and metaconglomerates. Metasandstone 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 symmetrical 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 2). Some general overviews of greenstone belt mineralization are published in Windley (1977) and Watson (1976). Wyoming greenstone belt reviews are available in Hauss (1982a) and Graft 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 Seminole 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 tacholites and selected samples have assayed only a trace, to no gold.

Harrer (1966) estimated that the Seminole Mountains host 50 to 100 million tons of iron ore resources contained in banded iron formations. Some gold is apparently localized in these metaexcidences (Levering, 1929, p. 230; Hauss, 1982a) although the extent of mineralization may be restricted. Two samples of altered iron formation near the Penn Mines on Bradley Peak (see sec. 6, T.25N., R.85W.) contained interesting amounts of gold (Table 2); however, samples collected elsewhere by Levering (1929) and by more recent exploration groups have reported only traces to no gold.

Although Friel (1976) reports significant scotabound 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 epigranitic 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 chalcopyrite. The veins are small and range from small sub-parallel quartz stringers to 3-feet-thick N.20°E. trending veins.

Epigenetic alteration which accompanies winning occurs as silification, carbonatization, and chloritization (Klein, 1981). Silification 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 2).

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 antiform 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; Hauss, 1980a).

| Table II. Assays of selected samples from the Bradley Peak area, Seminole Mountains (after Hauss, 1981). |
| Sample No. | Sample Location | Gold oz/ton | Sample Description |
| 5081 | E/6 E/6 Sec. 6, T.25N., R.85W. | 2.87 | Selected quartz vein sample from mine dump |
| 6761 | NE/4 NW/4 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 silicic 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 silification 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 a. 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 veins clasts in a pyritic, sericitic matrix. The radioactive conglomerates are apparently derived from a nearby source and deposited unconformably on metasalts of the upper Phantom Lake Suite (Karlstrom and Holston, 1979). The remainder of the Magnolia Formation consists of a fining upward quartztite 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 (anomalous, 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 formed in situ, but now are recovered in deposits for which there are no records. The deposits are known as "kurozome" or "kurozome group" deposits in Japan, and are often associated with metamorphic rocks, particularly gneisses and granites. These deposits are typically found in areas that were subjected to high temperatures and pressures, such as metamorphic belts and orogenic belts, where the radioactive minerals are concentrated and preserved.

**Genesis**

Metamorphic processes are responsible for the formation of uranium deposits. In particular, the process of metasomatism, which involves the movement and redistribution of chemical elements within rocks, plays a crucial role in the formation of these deposits. Metasomatism can occur as a result of intense heat and pressure, which can lead to the formation of new minerals. In the case of uranium deposits, the process of metasomatism is often associated with the movement of fluids that contain uranium, leading to the concentration of uranium in certain areas.

**Massive Sulfides**

South of the Mullen Creek-Nash Fork Shear zone in the southern Sierra Madre, Medicine Bow, and Laramie Range is a series of amphibolite metamorphic grade eugeoclinal Middle Proterozoic (1.9 to 1.6 b.y.) metamorphics (Figures 1 and 2). These are intruded by granite 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 Madre and grouped into the Green Mountain Formation (Divis, 1976, 1977). The metabasics of the Green Mountain Formation are interpreted to have been deposited in an island arc 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 volcanoclastics with mafic to felsic compositions. Relic volcanoclastic textures, such as vesicular, angular, and porphyritic, are recognizable at some localities (Divis, 1977).

**Uraniferous Conglomerates**

The southeastern edge of the Wyoming province is overlain by thick piles of Late Proterozoic low-grade meta-sediments (Figure 1). These supracrustals were deposited in epicontinental and minor intrasabasal basins along the southeastern margin of the Archean craton. The metamorphic effects are nonconformable to the host rocks, and the thicknesses are at about 2.5 b.y. (Karrlson and Houston, 1979).

These metasomatism have been mapped in the northern Sierra Madre and Medicine Bow Mountain by Graff (1978) and Karrlson (1981). The lower succession is characterized by the Precambrian basement, and the upper succession is characterized by the Late Archean to Early Proterozoic. The heavy minerals in the lower succession were concentrated by stream action and are believed to represent the fluvial placer deposits (Houston and Karrlson, 1979; Karrlson and others, 1981). This process of concentration of the heavy minerals in the fluvial systems is the mechanism by which the placer deposits are formed.

**Mineralization**

From an exploration standpoint quartz pebble conglomerates are not only a source of uranium, but also a source of gold. Similar conglomerates are mined for uranium in Blind River, Canada, and for gold and uranium in the Windermere Range of China. As much as 0.14 percent uranium (anomalous), and 10 ppm gold (PraflGraff, pers. comm., 1981) have been reported in association with the Wyoming conglomerates. Pyrite grains generally comprise a few tenths to as much as 10 percent of the conglomerates (Karrlson and others, 1981). Radiometric heavy minerals are coenitite, thorite, thortovite, monazite, huttonite (Z), and zircon. These heavy minerals and thorium minerals are in masses that may have been formed in situ, but now are recovered in deposits for which there are no records. The deposits are known as "kurozome" or "kurozome group" deposits in Japan, and are often associated with metamorphic rocks, particularly gneisses and granites. These deposits are typically found in areas that were subjected to high temperatures and pressures, such as metamorphic belts and orogenic belts, where the radioactive minerals are concentrated and preserved.
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 metagneous 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 reeved quartz veins and veinlets and as fracture fillings in cataclasites 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 ir 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).
With further exploration, some of these deposits will undoubtedly be reclassified as stratabound volcaniclastic (Hedlund, 1980a, 1982a). The tectonic setting, along with a considerable volume of felsic metavolcanics, are favorable factors for the deposition of volcaniclastic massive sulfides similar to the Kuroko type (i.e., see Franklin and others, 1981, p. 531-536).

Massive sulfides within the Hutton-Fletcher Park area are sporadically associated with metatellurite and brecciated metavolcanics. The metatellurites are pyritized and display good quartz vein textures. Metavolcanics at the Hutton Mine (sec. 14, T.13N., R.60W.) are intensely altered felsic (rhyolites/andesites). The mineralization associated with the altered rock occurs as massive pyritized iron formation. Hand specimens of rocks from the mine dump contain the pyrite: the pyrite exhibits coliform texture mantled by chlorite schist 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 Hutton Mine. Within a few hundred feet to the north of the tremay shaft are recognizable volcaniclastic breccias (mill rock) containing felsic fragments up to eight inches across in a chloritized matrix. Similar volcaniclastic breccias have been used successfully as a guide to massive sulfides in Canada (Schnellmann, 1973). A similar deposit by Osterwald and others (1966) of an ore specimen (obviously selected) from the Hutton Mine produced 17.92 percent copper and 0.05 ounces of gold per ton.

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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 metagreywacke 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 rehual quartz veins and veinlets and as fracture fillings in cataclasites and mylonites in the immediate area. The host granodiorite exhibits medium-grained, porphyritic to foliated textures while the quartz monzonite has medium-grained to aplite 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 a petrographic 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 specimens (Hauel and Jones, 1982). The propylitic zone was defined on the appearance of increased amounts of epidote, chlorite, and sulfides. Drilling has substantiated lower-grade reserves of 35 million tons of 0.21 percent copper and 0.02 ounces per ton gold (Nevin, 1973).

**FIGURE 4. Massive pyritized coliform ore from the Hutton Mine. The pyrite is mantled by chalcopyrite.**

**Genesis**

Many of the sulfide deposits in the southern Sierra Madre and Laramie Range are volcaniclastic. Some of these deposits in the Sierra Madre are characteristic of proximal or of distal volcaniclastic 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 Irons ores 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 a relationship 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 Imary ores, more diversified ore mineralizations 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 Imary Mine on the eastern boundary of sec. 16, T.13N., R.60W., a mineralized rock outcrop is stained with tenorite, malachite, and spotty marcasite, suggesting a more diversified mineralogy in this nearby area. However, the lack of fragmental rocks near this minor copper-zinc deposit would suggest that it is more characteristic of distal deposition rather than proximal at the Imary Mine.

The Silver Crown ores are epigenetic hydrothermal. Each deposit exhibits some form of hydrothermal alteration, and the mineralizing events probably occurred during the last two stages of the emplacement of the Sherman Granite Batholith or later. The Sherman Granite was emplaced at about 1.4 billion years ago (1964). The Silver Crown is located in a northeast-trending shear at the mine site (McCallum and Orbach, 1968, plate 1).

The Sherman Granite at the Rambler Group in the Curtis Goodly State Park on the western edge of the district is hydrothermally altered to propylitic assemblage (Hauel and Jones, 1982). The granite also contains copper-zinc mineralization associated with the hydrothermal alteration. These 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 felsic magmas which produced 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 4). The shear is interpreted as a fault that is localized by the primitive oceanic crust collided with the Archean craton. The shear zone is as much as 4 miles wide and consists largely of cataclasites (Hooston and others, 1968). The shear zone cataclasites contains scattered mineral deposits.

**Geology**

Several mines were developed in shear cataclasites along the Mullen Creek-Nash Fork shear zone during the late 1800's (Curry, 1965; McCallum, 1968; McCallum and Orbach, 1968). The mine was located in the west of the area. The mineralization is principally for gold, copper, and platinum mineralization.

One of the better mineral properties was the New Rambler Mine (sec. 33, T.13N., 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 tholeitic mafic body. The abundant rock type in the area is medium- to coarse-grained metadiorite and metabasalt that grades downward into metagreywite and metaperidotite (McCallum and others, 1976).

An intense regional shearing is responsible 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 Orbach, 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 hornfels and calcite pegmatite, while biotite, generally, was unaffected. The propylitic alteration products include chlorite, epidote, dolomite, albite, magnetite, and sericite. Biotite 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 Malic Series rocks. Primary copper-gold-platinites which are localized to faults, and quartz veins where they cut the Malic Series rock units. The precious metals are associated with fracture and breccia forming sulfides and arsenides; these deposits are spotty, and are apparently of limited extent.

**McCallum and others (1976)** suggest two possible origins for the shear zone metamorphic 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 tektontically 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 strata-bound 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 gysiferous 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 (Knis, 1977). Inland sebkhas were depositional sites for gypsum, gysiferous 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
Metals at the New Ramber are associated with hydrothermal alteration processes, and 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 cataclastic rocks as replacements.

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

**RED BED COPPER: SILVER**

Several red bed sandstones of Late Paleozoic through Mesozoic age in western Wyoming and southwestern Idaho contain some interesting copper and silver deposits. These deposits are associated with the formation of the Salt Lake (Jurassic) and Idaho carbonate (Eocene) formations, 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 miogeoclinc. During the Early Cretaceous, this region was affected by intense tectonism which produced complex folding and faulting that continued until the Tertiary, forming the Overthrust Belt. This area 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 mined. A small tonnage of copper was mined from the Westmont deposit in the early 1900's (Manfield, 1927). A slightly greater tonnage was shipped from the Griggs and Ferney Gulch properties in the Lake Alice district of Wyoming (Lloyd, 1970, p. 131-134).

At Montpellier, Idaho (Figure 5) the copper deposits are found in the Thaynes Sandstone Member of the Thaynes Limestone. The copper occurs as malachite and azurite veins on joint surfaces and along the bedding planes of massive calcareous sandstone and shale units. At depth, in mine workings, several sulfide zones were intercepted. The recognized sulfides include chalcopyrite and covellite replacements of organic debris. The mineralization is strata-bound although the mineralized zones are irregular and not confined to any particular bedding plane in the stratum. Manfield (1927, p. 346) reports that 70 tons of hand samples are containing 18 percent copper were shipped from the Montpellier claim (sec. 27, T.33S., R.45W.), located east of Montpellier. 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 gysiferous 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 (Kamins, 1977). Inland sebkhas were depositional sites for gysiferous siltstones and claystones. Carbonates were formed in small lakes between dunes (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, (Bloch, 1983). Wherever the sandstone is mineralized, the host red bed has been bleached or altered in contrast to the typical dull hematite-stained unaltered rock (Love and Antweiler, 1973; Husel, 1982).

In this area, 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 in the Nugget. Identified ore minerals include malachite, azurite, tenorite, and chalcocite. Cookies were sampled from the preceeded adit up to an elevation of 7,500 feet (75 feet, 5,000 feet, 1,500 feet, 750 feet, 500 feet), 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 1.1 percent copper, 0.52 ounces per ton silver, 137 ppm zinc, and a trace (63 ppm) of cobalt.

At Spring Lake Creek (SE1/4 sec. 24, T.28N., R.117W.), 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 copper, 100 ppm cobalt 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 1).

**Genetics**

There are a few characteristics which are apparent in unearthing the genesis of the Nugget Sandstone deposits: (1) the mineralized portions of the deposit are situated 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, 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 Montpellier, Idaho deposits); and (4) at the Griggs Mine, the major mineralization seems to be associated with bleached and altered sandstone. Love and Antweiler (1973) suggest that these mineralized zones in these red beds were derived from metal-bearing fault zones, even though no petroleum has been observed at the mineralized sites. It is suggested that metaliferous fluids migrate into and through the permeable sandstone units, and that the overlying impermeable gypsum beds block the flow of some of the fluids.

*To convert ppm (parts per million) to percent, multiply the ppm by 10^-6, such that 10,000 ppm = 1.0%.*

**Gypsum beds. Breaching, 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, 1962).

The petroleum would not only provide a source of metals but also a reducing environment to bleach the red beds. A source for the breaching of the overlying gypsum beds from sulfate ions leached from the overlying gypsum beds. Sulfate bacteria ferried on the hydrocarbons would reduce the sulfite ions to sulfur 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 interstitial, mobilized by compaction and dia-genesis, and localized by rare organic debris or H2S should also be considered. Thus, a mode of genesis has been proposed for the Montpellier deposit. The metaliferous fluids from the mineralized zones, the Montpellier 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 materials were reduced. The organic debris found in the Triassic Sandstone would act as a reducing agent, and H2S-producing bacteria could provide an excellent source of sulfur to precipitate metallic sulfides.

**Porphry Copper-Molybdenum Deposits**

**Introduction**

Several volcanic centers in the Absaroka Mountains of northwestern Wyoming are characterized by disseminated, stockwork, and vein mineralization, and hydrothermal alteration, characteristics 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 Lower and Middle Tertiary porphyry copper model, although similarities to the Diorete Model (Hollister, 1974; 1978) may also be present, but less common.

The mineralized centers (Figure 6) are characterized by a central intrusiv complex. Adjacent to the intrusive complex are breccia complexes, ore shoots, and mineralized breccias, sulfide, quartz and calcite veins, and some massive sulfide bodies. The distribution of the vein and breccia structures is controlled by structural fabrics and tectonic features. The tectonic and magmatic framework is dominated by large north-south trending faults and the intersection of a north-northeast-trending zone with the regional fabric. The volcanic rock assemblage is dominated by andesite and dacite tuffs and flows. The volcanic rocks are well developed in the northern part of the basin, where they form the cores of volcanic structures and the flanks of large volcanic complexes. The volcanic rocks are cut by a number of small stocks of diorite, quartz diorite, and granodiorite.

Mineralization is associated with these volcanic centers generally occurs as disseminations and stockworks in intensely altered rocks, and in fractures and veins that trail off 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
TABLE III. Assays from mineralized red bed arenite samples collected in the Overthrust Belt of western Wyoming.

<table>
<thead>
<tr>
<th>Prospect</th>
<th>Location</th>
<th>Cu (percent)</th>
<th>Zn (ppm)</th>
<th>Pb (ppm)</th>
<th>Ag (ppm)</th>
<th>Co (ppm)</th>
<th>Reference</th>
<th>Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Griggs Mine</td>
<td>7-28N-117W</td>
<td>0.02-6.7</td>
<td>26-31,000</td>
<td>tr.-5000</td>
<td>tr.-1200</td>
<td>tr.-20</td>
<td>Love &amp; Antweiler, 1973</td>
<td>Nugget</td>
</tr>
<tr>
<td>Ferney Gulch</td>
<td>1-27N-118W</td>
<td>5.0</td>
<td>26,000</td>
<td>500</td>
<td>tr.</td>
<td>700</td>
<td>Love &amp; Antweiler, 1973 Geol. Survey of Wyo. files, 1982</td>
<td>Nugget</td>
</tr>
<tr>
<td>Spring Lake Creek</td>
<td>24-28N-117½W</td>
<td>0.21-0.25</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>Love &amp; Antweiler, 1973 Geol. Survey of Wyo. files, 1982</td>
<td>Nugget</td>
</tr>
<tr>
<td>Coantag</td>
<td>NE½ 36-28N-117½W</td>
<td>0.39</td>
<td>32</td>
<td>---</td>
<td>2</td>
<td>---</td>
<td>Love &amp; Antweiler, 1973</td>
<td>Nugget</td>
</tr>
<tr>
<td>Landslide Dam</td>
<td>20-28N-117W</td>
<td>0.086</td>
<td>22</td>
<td>---</td>
<td>1</td>
<td>---</td>
<td>Love &amp; Antweiler, 1973</td>
<td>Nugget</td>
</tr>
<tr>
<td>Big Park</td>
<td>E½ 12-27N-117½W</td>
<td>*</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Love &amp; Antweiler, 1973</td>
<td>Nugget</td>
</tr>
<tr>
<td>Cabin Creek</td>
<td>SW½ 37N-114W near headwaters of Cabin Creek</td>
<td>*</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Love &amp; Antweiler, 1975</td>
<td>Nugget</td>
</tr>
<tr>
<td>Halfturn Creek</td>
<td>NE½ 37N-115W near headwaters of Halfturn Creek</td>
<td>3.0</td>
<td>70</td>
<td>150</td>
<td>---</td>
<td>---</td>
<td>Love &amp; Antweiler, 1973</td>
<td>Nugget</td>
</tr>
<tr>
<td>Green River Lakes (Mill Creek)</td>
<td>43° 19'/109° 51'</td>
<td>*</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>R.E. Harris, Geol. Survey of Wyo. files, 1983</td>
<td>Nugget</td>
</tr>
<tr>
<td>Cabin Creek Campground</td>
<td>43° 15'/110° 47'</td>
<td>0.15</td>
<td>23</td>
<td>trace</td>
<td>---</td>
<td>---</td>
<td>Geol. Survey of Wyo. files, 1982</td>
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<tr>
<td></td>
<td></td>
<td>6.80</td>
<td>150</td>
<td>5600</td>
<td>0.9</td>
<td>30</td>
<td>R.E. Harris, Geol. Survey of Wyo. files, 1983</td>
<td>Nugget</td>
</tr>
<tr>
<td>Watercress Canyon</td>
<td>NW½ 4-22N-118W</td>
<td>0.1-7.5</td>
<td>70-360</td>
<td>30-700</td>
<td>0.6-2.7</td>
<td>---</td>
<td>Rubey and others, 1975 Wells</td>
<td></td>
</tr>
<tr>
<td>Cockscamb</td>
<td>19N-120W</td>
<td>*</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Osterwald and others, 1966</td>
<td>Beckwith</td>
</tr>
<tr>
<td>Teton Pass</td>
<td></td>
<td>*</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>J.D. Love, pers. comm., 1982</td>
<td>Nugget</td>
</tr>
</tbody>
</table>

* sample stained with copper carbonates — no reported assays.
TABLE III. Analyzes from mineralized and non-mineralized samples collected in the Overthrust Belt of western Wyoming.

<table>
<thead>
<tr>
<th>Location</th>
<th>Reference</th>
<th>Sample Location</th>
<th>Sample Location</th>
<th>Sample Location</th>
<th>Sample Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Happy Jack</td>
<td>R.M. Harris, Gly</td>
<td>304-014</td>
<td>130-014</td>
<td>150-014</td>
<td>190-014</td>
</tr>
<tr>
<td>Big Pine</td>
<td>R.M. Harris, Gly</td>
<td>304-015</td>
<td>130-015</td>
<td>150-015</td>
<td>190-015</td>
</tr>
<tr>
<td>Silver Creek</td>
<td>R.M. Harris, Gly</td>
<td>304-016</td>
<td>130-016</td>
<td>150-016</td>
<td>190-016</td>
</tr>
<tr>
<td>Fool Canyon</td>
<td>R.M. Harris, Gly</td>
<td>304-017</td>
<td>130-017</td>
<td>150-017</td>
<td>190-017</td>
</tr>
<tr>
<td>Ophir</td>
<td>R.M. Harris, Gly</td>
<td>304-018</td>
<td>130-018</td>
<td>150-018</td>
<td>190-018</td>
</tr>
<tr>
<td>Bighorn Park</td>
<td>R.M. Harris, Gly</td>
<td>304-019</td>
<td>130-019</td>
<td>150-019</td>
<td>190-019</td>
</tr>
</tbody>
</table>

**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 great magnitude 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 less 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 andesic material of the shoshonite suite. The genesis of these ultra-potassic flows is discussed by Proski (1973), and their genesis will not be elaborated here.

The tremendous volume of volcanic material (greater than 7,000 cubic miles) is erupted from several volcanic centers that lie along a north-northwesterly trend. The location 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 Absaroka grade outward into well-beded deposits of epistromatically reworked volcanic debris comprising well-sorted volcanic breccia, conglomerate, sandstone and tuff (Lipman and others, 1972). These volcanioclastic 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 volcanioclastics are teared the Absaroka Supergroup. Generally, the Absaroka Supergroup averages greater than 5,000 feet thick (Smidt and Proski, 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 veins 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) synepigenetic 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 alteration characterized by a typical alteration assemblage. The intrusive centers, the deuteritic alteration takes on the effects of hydrothermal propylitic alteration. Generally, the presence of veins or veins of calcite, epidote, chlorite and pyrite in the propylitically altered rock signifies that the deuteritic altered rock has been overprinted by hydrothermal 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.

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ALKALIC AND PERALKALIC TERTIARY INTRUSIVES AND ASSOCIATED METALS
Six separate alkalic to peralkalic 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 Missoula Buttes, Sundance Mountain-Green Mountain, and Inyan Kara Mountain intrusives. Of these, only the Bear Lodge and Mineral Hill intrusives are associated with apparently 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, syenodolerites, lamprophyres, and dolerites.

These rocks are alkalic to peralkalic 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 orebodies are associated with these rocks.

The Black Hills are complex with 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 Lashe, Zaïre; 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 peralkalic magmas. Differentiation within the alkali 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 3.0 percent U3O8 at the Surtrise Lode (secs. 21 and 22, T.52N., R.63W.) and in amounts greater than 0.05 percent U3O8 at other locations (Harris and Hauser, 1983). Prospecting for rare earth minerals and niobium has centered about the northern carbonatite. A previously unreported carnotite 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 pyroclastic deposits.

The Bear Lodge Mountains intrusive may also contain significant thorium resources. The U.S. Geological Survey has undertaken a study of this thorium occurrence, and preliminary work by Mortimer Staats has been published (Staats and others, 1979). Work by the U.S. Geological Survey delineates 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 (Dean, 1966). A value of 10.1 ounces per ton gold was reported by Roberts Jones (personal communication). Harris, 1982) from a chip sample of altered trachyte from sec. 20, T.52N., R.62W. Previously, no gold assayed from material collected 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 S3 sec. 29, T.52N., R.60W.

Copper mineralization in the Black Buttes area, located to the west of Mineral Hill, is found as scattered, unpredictable pockets replacing limestone (Huald, 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 separation in silicic, alkalic magmas from normal aluminia silicate magmas by differential melting at relatively low temperatures (Robinson, 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 (Balley, 1974). The African rift is an example where carbonatite lavas are being extruded from active volcanoes such as Ololoyong 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-Diablo’s Tower area eastward into South Dakota. The Bear Lodge Mountains intrusive is apparently the most highly differentiated and consequently the most alkalic pluton reported from this belt.

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