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ECONOMIC MINERAL DEPOSITS OF WYOMING — A REVIEW

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ECONOMIC MINERAL DEPOSITS OF WYOMING — A REVIEW

W. DAN HAUSEL[1]

INTRODUCTION

Although historical records are not clear, hematite may have been the first ore mined in Wyoming. Osterwald and others (1966) reported that hematite was mined by Indians for use as war paint. It is doubtful, however, that much hematite was extracted for this purpose.

By 1842, Wyoming was prospected for gold (Raymond, 1870). Gold discoveries were recorded in a number of areas by the end of the 1860's. By the early 1870's, several mining ventures were organized, and gold ore was stamped in several districts (Figure 1). The most notable district was the Sweetwater located in the South Pass area. Significant production of base metals began in 1899 with the development of copper mineralization in the Encampment District. Copper mines were active in this region until about 1908. During the World War I effort, 1916 to 1918, base metals (principally copper) were also mined in the Hartville uplift. After 1918, only insignificant copper production was reported in the state.

During the last half of the 19th century and the first half of this century, Wyoming's mining industry concentrated on the location and development of precious and base metals. Later, with the evolution of an industrialized nation, the minerals industry diversified, and sought many industrial minerals and metals as well as mineral fuels.

In recent decades, uranium exploration has only been surpassed by exploration for oil and gas. This uranium exploration has concentrated on locating extensive roll-front uranium mineralization in Tertiary arkosic sandstones. Wyoming's large, sediment-filled Tertiary basins make the state a uranium-explorationist's paradise. In addition to uranium, commercial deposits of trona, high-swelling bentonite, carbonates, anhydrite, phosphate, iron-formations, sand, gravel, and other construction materials have also become important mining commodities. With favorable market conditions, these deposits will continue to be mined in significant amounts.

During the last fifty years, however, base and precious metals have been notably absent from production statistics. Favorable geological environments coupled with more favorable markets suggest that these metals may once again attract exploration.

Wyoming's mineral deposits occur in various physiographic areas. These physiographic areas are characterized by north-trending, roughly arcuate mountain ranges separated by broad basins. Only about 10-15 percent of the state's surface area are formed by Precambrian-cored uplifts and Tertiary volcanics. The remaining areas are broad basins filled with sedimentary rocks.

The historic metal-producing regions are scattered throughout several mountainous regions in the state, with many of the districts lying within Precambrian greenstone belts, shear-zone tectonites, island-arc type volcanogenic schists, and Tertiary volcanics.

Major nonmetal and fissionable metal deposits, for which the state is well-known, occur in detrital, marine, and lacustrine sediments. The major uranium and trona deposits are found in Tertiary sediments in basin centers, whereas economic bentonite deposits are usually found in Cretaceous strata on the flanks of basins.

Many of Wyoming's more significant mineral deposits are briefly discussed in light of their geological environments and host rocks. The discussions are organized by geological age, beginning with the Precambrian.

GEOLOGIC SETTINGS FOR PRECAMBRIAN MINERALIZATION

The Precambrian of Wyoming is conveniently divisible into two groups: (1) a basement of Archean (>2.5 b.y.) gneissic terrain with interspersed

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greenstone belts and (2) a basement of Early to Middle Proterozoic (1.9 to 1.6 b.y.) volcanogenic schists. These two basements, or provinces, meet in southeastern Wyoming and are separated by the Nash Fork-Mullen Creek shear zone (Houston and McCallum, 1961; Houston and others, 1968) (Figure 2). The older Archean terrain is termed the Wyoming province (Houston and Karlstrom, 1979).

The Archean rocks of the Wyoming province consist of relatively unmineralized gneisses, migmaties and granitic plutons and batholiths with isolated greenstone belts (Bayley and others, 1973; Condie, 1976; Gliozzi, 1967; Houston and Karlstrom, 1979). The greenstone belts, which are generally thought to be formed in back arc basins, are commonly enriched in metals (Windley, 1979).

Greenstone belts typically consist of a volcanic and sedimentary group. The volcanic group is generally ultramafic to mafic volcanogenic schists that grade upward into mafic and felsic schists. The volcanic group is overlain by a predominantly sedimentary group of chemical precipitates (e.g. cherts, jaspers, taconites). Structurally, greenstone belts are folded, fractured, and intruded by granitic magmas and metamorphosed to an amphibolite or greenschist facies. In their simplest form, greenstone belts are linear in plan and form deep

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Figure 1: Remains of the early gold mining history of Wyoming. (a) Gold ore stamps, (b) winch, and (c) stamp mill located in the Centennial Ridge area. Photographs by W. Dan Hausel, 1980.

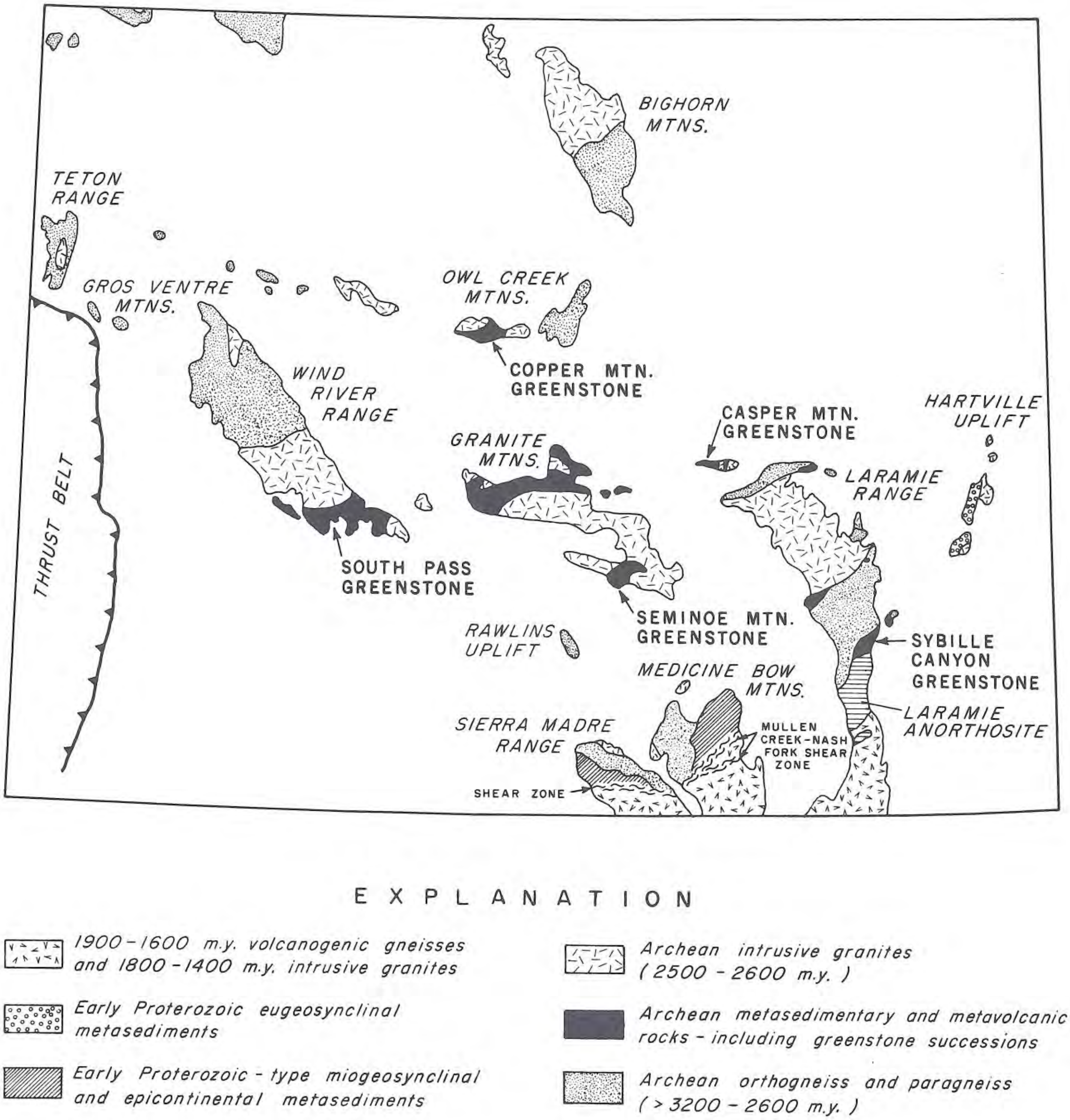


Figure 2: Location map of the Wyoming greenstone belts (after Condie, 1976; and Houston and Karlstrom, 1979). The greenstone belts are the South Pass (Bayley and others, 1973; Hausel, 1980a), Copper Mountain (Duhling, 1971; Gliozzi, 1967; Granath, 1975; Hausel, 1981a; Houston, 1973), Granite Mountains (Houston, 1973; Love, 1970; Peterman and Hildreth, 1978), Seminoe Mountains (Bayley, 1968; Bishop, 1964), Casper Mountain (Beckwith, 1939; Hausel and Glass, 1980); the Central Laramie Range (Graff and others, 1981); and two small belts in the central and northern Laramie Range.

synclinal basins in cross section. Favorable hosts for mineralization include quartz veins, mafic-felsic volcanic contacts, and some metasediments (Windley, 1979).

The South Pass greenstone belt is the most extensively studied greenstone in Wyoming because of important iron-formations and lode gold (Bayley and others, 1973; Hausel, 1980a; Houston and Karlstrom, 1979). The volcanic group of the South Pass greenstone includes pillowed and amygdaoidal metabasalt, metatuff, meta-andesite, hornblende schist and amphibolite, which are mapped as the Roundtop Mountain Formation (Figure 2). The sedimentary group includes both the Goldman Meadows and Minerals Delight formations. These rocks include metagraywacke, peltic schists, conglomerate, quartzite and iron-formation. Intrusive phases are serpentinite, metagabbro, metadacite and the Louis Lake granodiorite.

These rocks were affected by at least two stages of deformation. During the initial stage of folding, northeast trending shear zones developed in structurally competent metagabbro and in less competent schist and graywacke. These shears formed conformable to the grain of the wall rock. Silicification followed shearing and resulted in fissure filling and replacement of much of the fractured country rock. Later stage faults acted as conduits for late stage quartz mineralization. This later stage mineralization is economically unimportant. Metamorphism is predominantely amphibolite grade with a small block of greenschist facies (Bayley and others, 1973).

The edge of the Archean province, in southeastern Wyoming immediately north of the Nash Fork-Mullen Creek shear zone, is overlain by younger Early Proterozoic marginal basins containing epicontinental, miogeosynclinal, and eugeosynclinal successions. These basins contain thick sequences (up to 8 miles thick) of metasedimentary and metavolcanic rocks deposited on the edge of the Archean craton 2.5 to 1.7 b.y. ago (Hills and others, 1968). In the vicinity of the Sierra Madre and Medicine Bow Mountains, the metamorphics are more typical of miogeosynclinal sedimentation.

Three successions of metasediments are recognized. The Phantom Lake suite is composed of metaconglomerates, quartzites, metalimestones, metadolomites and felsic and mafic schists. The Deep Lake Group contains metaconglomerates, quartzites, phylitic schists, and metatillite, and the Libby Creek Group contains metadolomite, metaphyllite, and quartzite (Houston and Karlstrom, 1979). These metasediments suggest epicontinental and miogeosynclinal deposition in a stable shelf environment. Quartz-pebble conglomerates interbedded in the metasediments may be important hosts for uranium mineralization. These conglomerates have important similarities to economic metaconglomerates mined in Canada and South Africa (Houston, 1979).

Metasediments found in the Hartville uplift are more typical of eugeosynclinal sedimentation than those in the Sierra Madre and Medicine Bows (Houston and Karlstrom, 1979). The most important recognized mineralization in the Hartville metasediments is iron-formations.

South of the Nash Fork-Mullen Creek shear zone, in the southern Sierra Madre, Medicine Bow, and Laramie Ranges are a series of Middle Proterozoic (1.6 to 1.9 b.y.) metamorphics that may have formed in an island arc environment and then accreted to the Archean craton 1.7 b.y. ago (Hills and Armstrong, 1974; Hills and Houston, 1979). These regions are discussed by Divis (1976, 1977); Houston and others (1968); and Klein (1974).

In the southern Sierra Madre, a series of calc-alkaline volcanics is grouped into the Green Mountain Formation. The Green Mountain Formation is composed of a series of mafic and felsic schists that often retain volcanogenic vesicular, agglomeratic, and porphyritic textures. These units were deposited in an island arc environment and later intruded by a number of post depositional granitic intrusives (Divis, 1976, 1977). The rocks retain several important similarities to rocks of the Canadian Superior province where stratibound volcanogenic massive sulfides are an important source of base and precious metals (e.g. see Anderson, 1969; Hutchenson, 1973; Kinkel, 1966; Lajore, 1977; Sangster, 1973).

There apparently were at least two major episodes of deformation in the Archean province prior to the deposition of the Proterozoic metasediments in southeastern Wyoming (Tweto, 1969). Additionally, Proterozoic metasediments on the edge of the craton were also deformed by their collision with the island arc system to the south of the shear zone.

The Nash Fork-Mullen Creek shear zone subdivides the Precambrian of Wyoming into an Archean basement to the north and a Proterozoic basement to the south. In places, the shear zone is 4 miles wide. Shear zone rocks are largely cataclastics. The shear zone runs through the central Sierra Madre and Medicine Bow mountains (Houston and McCallum, 1961; Houston and others, 1968). In the vicinity of the Laramie Range, the shear zone is projected through the anorthosite complex. It is again picked up in the Richeau Hills on the eastern flank of the Laramie Range (Graff and others, 1981). Shear zone cataclastics are hosts for base and precious metals.

At about 1.5 b.y., the Nash Fork-Mullen Creek shear zone was intruded by an anorthosite batholith at the present location of the Laramie Range. The anorthosite forms a complex of aluminum-rich feldspar rock with pods of magnetite-ilmenite.

At 1.4 b.y., southern Wyoming was intruded by granitic magmas. The Sherman granite in the southern Laramie and southeastern Medicine Bow mountains was emplaced at this time (Peterman and others, 1968).

Figure 3: View of the Gold Nugget stamp mill. In addition to South Pass, several greenstones were prospected for lode gold, such as the Gold Nugget camp in the Copper Mountain area. Gold mineralization occurred in quartz veins and along felsic and mafic schist contacts. Mined tonnages were small, and the amount of stamped ore was limited (Hausel, 1981a). Photograph by W. Dan Hausel, 1981.

PRECAMBRIAN MINERAL DEPOSITS

A number of syngenetic and epigenetic mineral deposits are recognized in the Precambrian. Important mineral deposits are recognized in the Precambrian. Important mineralization includes both syngenetic iron-formations and epigenetic gold lodes in the Archean greenstone belts. No syngenetic gold mineralization is recognized in the Archean greenstones. Proterozoic mineralization includes uraniferous conglomerates and iron-formation in geosynclinal successions, syngenetic and epigenetic base metals in island arc metavolcanics and metasediments, epigenetic base and precious metal mineralization in shear zone cataclastics, and some anorthosite and pegmatitic deposits.

Iron ore and gold in greenstone belts

Greenstone belts throughout the world are known for their important resources of precious, base, iron, ferroalloy and industrial metals (Fripp, 1976; Watson, 1976; Windley, 1979). The most important recognized greenstone mineralization in Wyoming includes iron-formations and lode gold.

In the Copper Mountain area (Figure 2), a band of (subeconomic) iron-formations extends easterly along the crest of the mountains for about 10 miles. These formations are primarily banded magnetite-silicates. Some minor disseminated and quartz vein copper is reported in the iron-formations near the McGraw Copper mine (Harrer, 1966). Auriferous quartz veins were prospected by numerous pits and mines in the Gold Nugget mining camp (Figure 3) (Hausel, 1981a), and some tungsten was additionally produced in the Copper Mountain region (Osterwald and others, 1966).

Mineralization in the Casper Mountain region includes gold- and silver-bearing veins (Hausel and Glass, 1980; Kinttel, 1978; Mokler, 1923) asbestos, chromite, and simple and complex pegmatites (Beckwith, 1939; Burford and others, 1979; Hausel and Glass, 1980; Osterwald and others, 1966). Several tons of beryl and feldspar have been mined from pegmatites in this area.

The Granite Mountains greenstone contains banded iron-formations, minor copper, lead, zinc, and gold (Harrer, 1966; Hausel and Glass, 1980; Love, 1970; Osterwald and others, 1966; Pekarek, 1977). Very little tonnage was mined.

Iron-formations, copper, and gold are reported in the Seminoe Mountain region (Bishop, 1964; Harrer, 1966; Hausel, 1981b; 1981c; Osterwald and others, 1966). Taconite deposits described by Bayley (1968), Harrer (1966), and Lovering (1930) in the Seminoe Mountains are extensive, with iron-formations containing about 100 million tons of ore. These deposits are siliceous magnetite-hematite bodies (Harrer, 1966).

In the South Pass greenstone, iron-formations are mined by U.S. Steel Corporation at their Atlantic City open pit mine. The mine site is located where the taconite was greatly thickened by internal folding and plication (Bayley and others, 1973). The taconite is composed of alternating iron-rich and quartz-rich layers that are notably lacking in carbonates and sulfides (Pride, 1969). About five million tons of taconite ore are mined annually, upgraded at the mine site to pellets, and shipped to the Geneva Steel Works smelter in Provo, Utah (Hausel and Holden, 1978). More than 80 million tons of taconite ore have been extracted since mining began in 1963.

Disseminated gold, in the South Pass area, occurs in arsenopyrite-quartz veins that generally follow the grain of wall rocks and occupy shear zones. These veins are often sheared themselves. The majority of the historic gold mines lie along northeast trending sheared metagabbros (Bayley and others, 1973) (Figure 4). The more productive mines were developed on ore shoots formed by vein intersections and near crests of anticlinal folds in the metagabbro (Armstrong, 1947).

The veins occur as massive quartz with abundant arsenopyrite. Accessory minerals include calcite, pyrite, chalcopyrite, native gold, and rare galena and pyrrhotite (Armstrong, 1947; Bayley and others, 1973; Osterwald and others, 1966; Spencer, 1916). Wall rock alteration is localized within 6 feet of most veins, and is expressed as potassic alteration immediately adjacent to the vein, with a broader zone of sericitization (Bayley and others, 1973).

The South Pass area was an active gold mining camp during the gold rush of 1870. It is estimated that as much as 325,000 ounces of gold may have been produced from auriferous-arsenopyrite-quartz veins and associated placers (Figure 5) (Hausel, 1980a).

Although only small amounts of metal and minerals have been produced from most greenstone belts in the state, these areas represent favorable exploration targets for economic mineralization. Homestake Mining's recent interest in the South Pass area suggests the potential importance of the greenstones.

To date, major stratiform gold mineralization

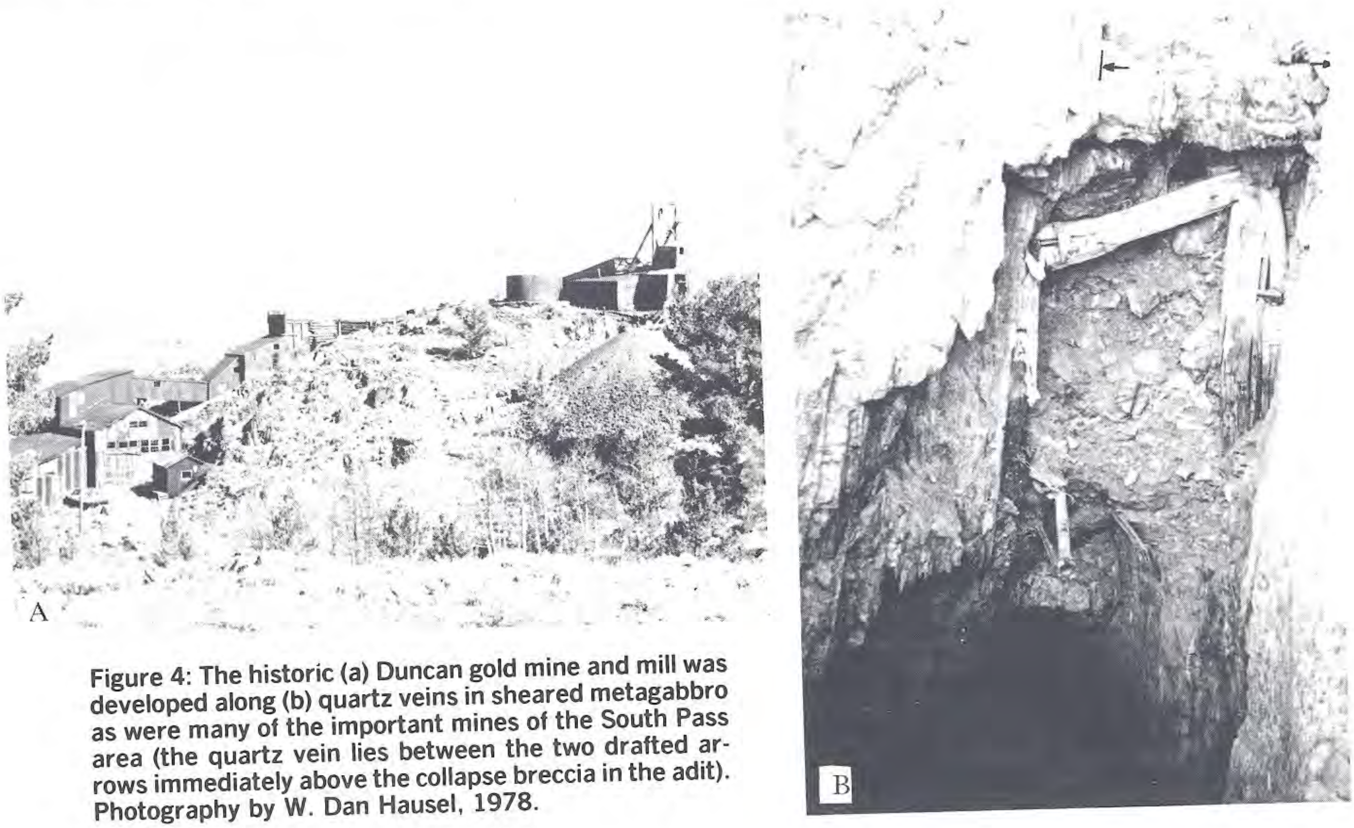


Figure 4: The historic (a) Duncan gold mine and mill was developed along (b) quartz veins in sheared metagabbro as were many of the important mines of the South Pass area (the quartz vein lies between the two drafted arrows immediately above the collapse breccia in the adit). Photography by W. Dan Hausel, 1978.

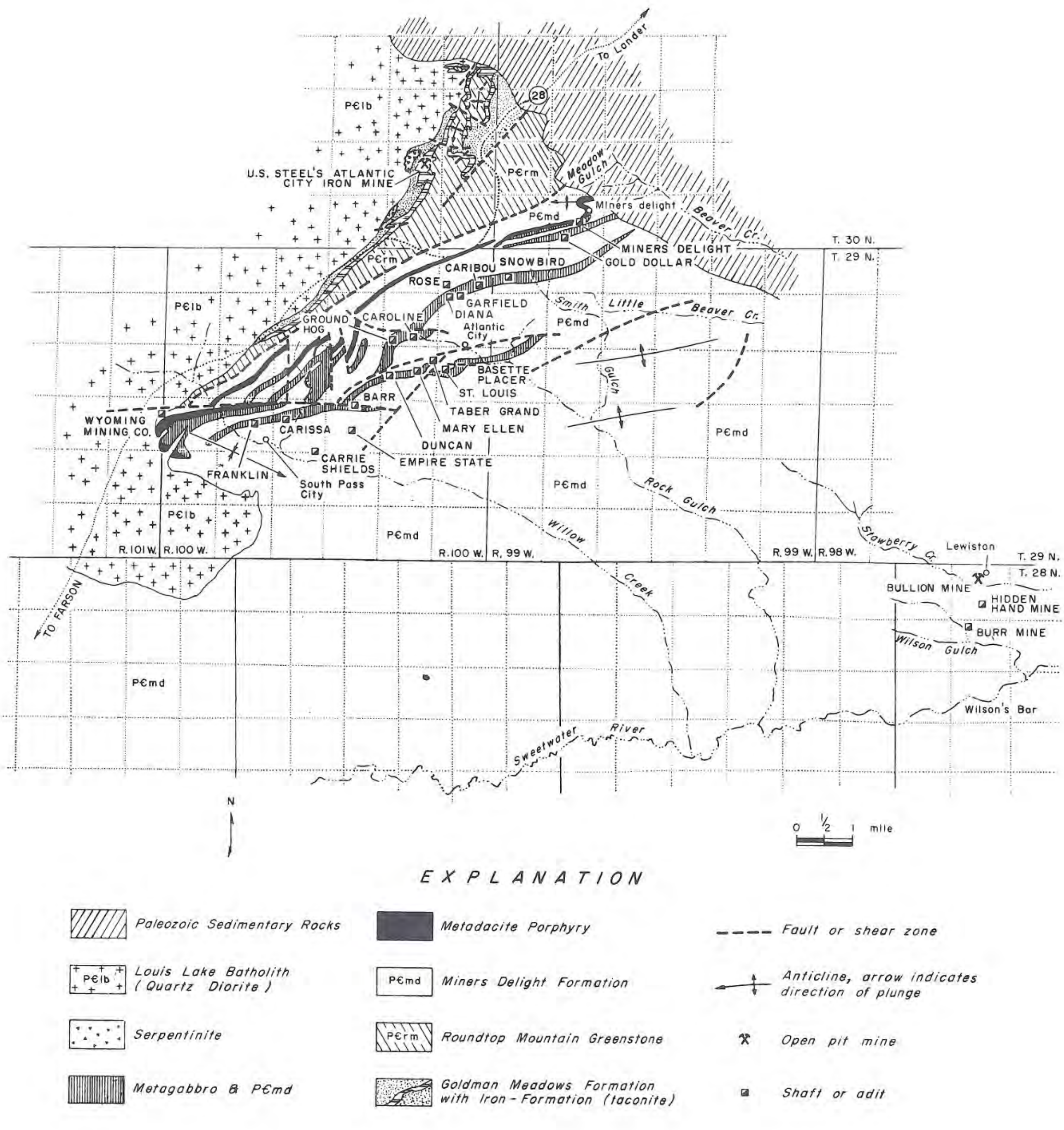


Figure 5: During the 1870's, the South Pass region experienced a gold rush. Four mining camps were organized — the South Pass, Atlantic City, Miner's Delight, and Lewiston (Armstrong, 1947; Bayley and others, 1973; Hausel, 1980a). Gold veins and placers were the primary targets of prospectors; and the more productive veins were associated with metagabbro instrusive phases (Bayley and others, 1973). Map modified from Bayley and others, 1973.

in banded iron-formations, and stratibound pyrite-sphalerite-chalcopyrite in differentiated mafic to felsic volcanics, have not been reported in the Wyoming greenstones. Because such deposits are mined in similar terrains in southern Africa and in the Great Lakes region (Fripp, 1976; Roberts, 1975; Spence, 1975; Windley, 1979), their potential existence in this state invites future exploration.

Uranium in metaconglomerates

Metaconglomerates in the Proterozoic miogeosynclinal successions of the northern Sierra Madre and Medicine Bow mountains are host to placer uranium mineralization. The conglomerates apparently were deposited in the continental marginal basins by southward flowing braided stream channels and other river systems. Detrital heavy minerals such as pyrite, gold, uranium and thorium were deposited in favorable placer traps. The basal conglomerate member of the Magnolia Formation of the Deep Lake Group shows promise for potential economic uranium mineralization. This member is radioactive and is found over large regions in both the Sierra Madre and Medicine Bow mountains. The unit is fluviatile and pyrite-bearing in radioactive zones. In places these radioactive zones are as much as 10 feet thick (Houston and Karlstrom, 1979). In addition to this conglomerate, other radioactive conglomerates are reported (Graff, 1978, 1979; Graff and Houston, 1977; Houston and Karlstrom, 1979; Houston and others, 1968, 1977, 1979; Karlstrom, 1977; Karlstrom and Houston, 1979a, 1979b; Karlstrom and others, 1981; Lanthier, 1979; Miller and others, 1977). As much as 0.14% U_3O_8 (Anonymous, 1981) and localized subeconomic gold (Paul Graff, pers. comm., 1981) are reported in the conglomerates.

Between 1975 and 1978, Exxon Minerals discovered significantly high radioactive anomalies in the One Mile Creek area of the Medicine Bow Mountains. The discovery led to a claim staking rush for the metaconglomerates (Houston and Karlstrom, 1979).

Iron ore and copper in eugeosynclinal successions

Significant iron-formation reserves and copper mineralization occur in eugeosynclinal metamorphic rocks in the Hartville uplift of southeastern Wyoming (Figure 2). The iron-formations occur within folded and faulted steeply dipping metasediments and metavolcanics that crop out on the eastern flank of the Hartville uplift. The iron-formation occurs in the Sunrise mine area, and to the west extends under gently dipping Paleozoic carbonates and sandstones. The Sunrise is the only active iron mine in the district (Figure 6). Iron ore has been mined in the district since 1898 (Harrer, 1966; Millgate, 1965; Osterwald and others, 1966).

Figure 6: Colorado Fuel and Iron Company's Sunrise Mine in the Hartville uplift. The mine has a rated annual capacity of approximately 600,000 tons. Hematitic iron-formations are mined, and the ore is shipped to C.F.&I.'s blast furnaces located in Pueblo, Colorado (Hausel, 1978). Photograph by W. Dan Hausel, 1980.

The extracted ore is shipped to Colorado Fuel and Iron Company's blast furnaces in Pueblo, Colorado, where it is used principally for making rails. Recent poor market conditions required C.F.&I. to place the Sunrise Mine on standby in the summer of 1980. If market conditions improve, the mine will again resume production.

The iron ore is described as a hematite schist formed from massive and specular hematite. The ore occurs in the lower part of the Good Fortune schist (Harrer, 1966; Millgate, 1965; Osterwald and others, 1966). Although some sulfides occur within these iron-formations, gold has not been reported in association with the ore.

Some copper and minor gold and silver were mined in the Hartville uplift in the past. These deposits are disseminated in metasediments and concentrated in quartz veins and stringers. Between 1916 and 1918, Wyoming produced 5,500,000 pounds of copper, most of which was mined in the Hartville District (Osterwald and others, 1966).

Copper in island arc volcanogenic schists

From 1899 to 1908, approximately 24,000,000 pounds of copper were produced in Wyoming. Much of this production was mined from the Encampment District in the southern Sierra Madres (Osterwald, and others, 1966). Since 1908, very little exploration and development has occurred in this region, although the potential for economic mineralization still exists.

The Green Mountain Formation, south of the Nash Fork-Mullen Creek shear zone in the southern Sierra Madre Mountains, has a number of characteristics that suggest potential deposition of volcanogenic massive sulfides (Hausel, 1980a). The schists in this formation form a series of amphibolite-grade metamorphosed calc-alkaline volcanic rocks and volcanogenic sediments deposited in an island-arc environment. A number of relic textures are retained by these metavolcanics such as vesicular, agglomeratic, and porphyritic textures (Divis, 1976, 1977).

Spencer (1904), Lindren (1908), and Osterwald and others (1966) report that these deposits generally contain pyrrhotite-chalcopyrite, pyrite-chalcopyrite, and galena-sphalerite-pyrite ores with small percentages of gold, and in places localized lead, zinc, nickel, cobalt, and traces of platinum. In general, the ore deposits occur as (1) disseminated mineralization in horneblende schist, (2) tactite-like garnet epidote streaks, (3) bedding replacement bodies in quartzitic layes in the schist, (4) in hornblendic contact metamorphic zones bordering diorite-gabbro intrisives, and (5) as quartz veins and pegmatites. Some deposits display massive pyritized colloform ore near volcaniclastics ("mill rock"?) suggesting important similarities to Superior Province massive sulfides (Figure 7).

In the Silver Crown District on the eastern flank of the Laramie Range, copper-gold ore deposits are localized in fault gouge and shear zones developed in metasediments. Drilling has substantiated several small ore bodies. At the Copper King Mine, 10 million tons of 0.30% copper and 0.038 ounces of gold per ton are indicated to a depth of 500 feet. Drilling additionally has shown that the ore body

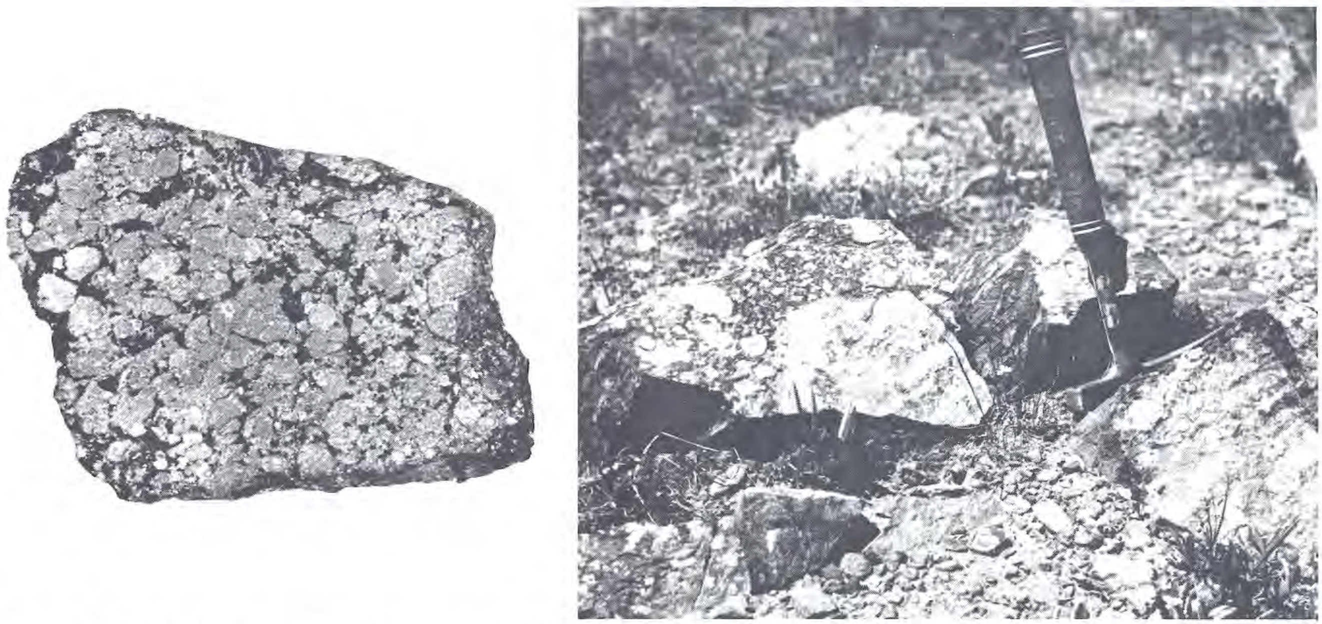


Figure 7: (a) Massive pyritized ore with colloform texture. This sample, collected in the Sierra Madres, exhibits rounded grains of pyrite mantled by chalcopyrite. The matrix is magnetite with minor chlorite. (b) Sierra Madre "Mill rock." Felsic volcaniclastics are often found in close proximity to massive ore. These felsic volcanic breccias are mapped in Canada and used as tracers to ore. Sangster (1973) dubbed these "mill rock" because whenever he was standing on a volcaniclastic with large fragments, he could hear the sound of a mill in the near background. Presumably, the volcaniclastics occur near minable ore and represent a fossil volcanic orifice from which the metallic sulfides originated. Photography by W. Dan Hausel, 1978.

continues to at least 700 feet depth before rapidly decreasing in size. The ore is epigenetic and possibly derived from the leaching of metasedimentary and metavolcanic rocks during the emplacement of the Sherman Granite batholith (Klein, 1974).

Shear-zone mineralization

The Nash Fork-Mullen Creek shear zone represents a boundary between the Archean basement (to the north) and the Proterozoic basement (to the south). The shear is interpreted as a fossil plate tectonic boundary where the primitive oceanic crust collided with the Archean craton. In places the shear zone is as much as 4 miles wide and consists largely of cataclastics (Houston and others, 1968). Mineralization of shear zone cataclastics is minor and only supergene enriched zones appear to have any important economic value.

Several mines were developed in sheared cataclastics in the early mining history of Wyoming (Currey, 1965; Hausel, 1980a, 1980b; McCallum, 1968; McCallum and Orback, 1968) principally for gold, copper, and platinum group mineralization (Figure 8). Only those deposits with supergene enrichment were developed to any great extent. The New Rambler Mine in the Medicine Bow Mountains was developed at an intersection of shears, and an extensive zone of supergene enriched ores were produced that commonly assayed 25 to 30% Cu with traces of platinum group metals (McCallum and Orback, 1968).

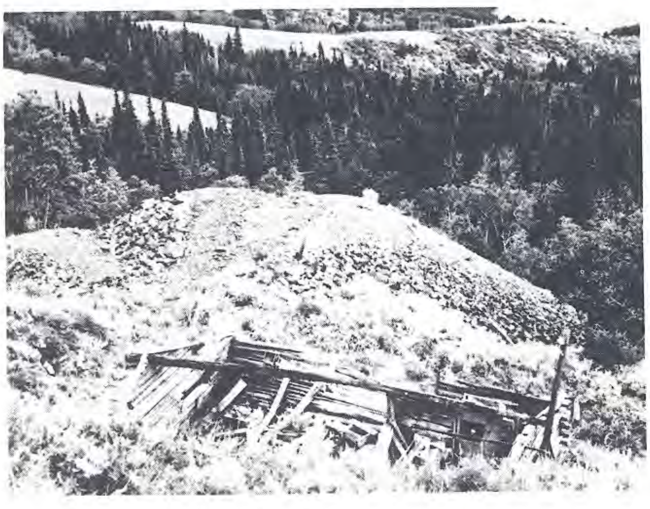
Many mines in the general area penetrated shear zones into copper, gold and platinum deposits. Mineralization in these shear zones occurred as fracture fillings and as stains on fractured and mylonitized surfaces (Figure 9). But for the most part, these were not developed to any great extent (Curry, 1965; Hausel, 1980b; McCallum, 1968).

The genesis of the ore solutions was probably hydrothermal. It is assumed that the metals were leached from enclosing mafic rocks during the Precambrian, and localized in shears. Remobilization of some mineralization may have occurred during Laramide tectonism (McCallum, 1968).

Late Proterozoic anorthosite and magnetite-ilmenites

During the Late Proterozoic (1.5 b.y.), the Nash Fork-Mullen Creek Shear zone at the present site of the central Laramie Range was intruded by anorthosite of batholitic proportions (Figure 2). The surface extent of the Laramie anorthosite covers about 350 square miles. The anorthosite obliterated any evidence of the shear zone within the Laramie Range, but sheared cataclastics are again visible immediately east of the anorthosite in the Richeau Hills (Graff and others, 1981).

The anorthosite, which is formed almost entirely of sodic feldspar, has been tested and



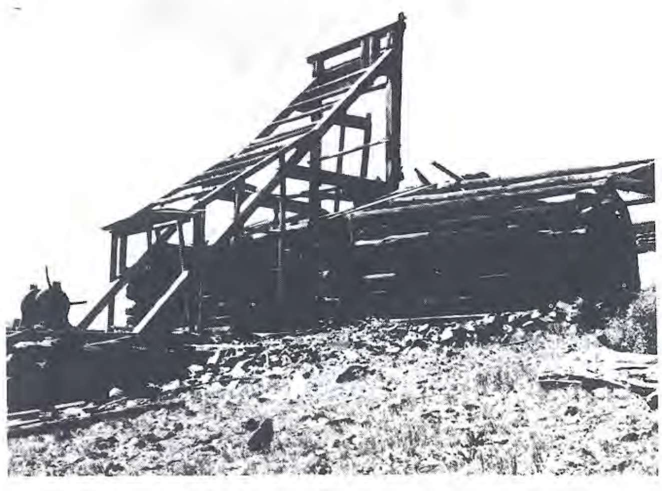


Figure 8: (a) View of the Platinum City mine dump and (b) Queen mine headframe in the Centennial Ridge District. Photographs by W. Dan Hausel, 1980.

examined for its aluminum potential (Harrer, 1954; Hagner, 1951), but presently the expensive process of separating aluminum from feldspar cannot economically compete with the mining of aluminum-enriched bauxites. However, the anorthosite does represent a potential resource for industrial minerals (Shutt, 1970; Hausel, 1981d). Large bodies of anorthosite, containing essentially no accessory minerals, could be economically mined for their sodium-rich feldspar to be used as a fluxing agent in glass production. Nearby resources of lime and glass sands in the Casper Formation are also available for use as stabilizing agents, and as a medium for glass, respectively (Hausel, 1981d; Osterwald and others, 1966).

The anorthosite contains rich-layers of magnetite-ilmenite formed by remobilization and concentration of iron and titanium during deformation of the batholith (Proffett, 1979). These deposits were economically mined in the 1960's and early 1970's by Plicoflex, Inc. for use as a heavy metal aggregate (Hagner, 1968; Osterwald et. al., 1966). However, this market is no longer available.

Miscellaneous vein and fissure-filling deposits

Several vein-type and fissure-filling base and precious metal deposits are found in the Precambrian. Most are poorly studied, small in size, and limited in tonnage.

In the Esterbrook District of the northern Laramie Range, ancient (Archean?) metasediments intruded by igneous bodies contain several fissure-filling and possible replacement deposits. Four groups of mineral deposits are recognized: (1) pyrrhotite-quartz-minor chalcopyrite, sphalerite, (2) galena-pyrite-calcite-quartz, (3) quartz-pyrite, and (4) quartz-feldspar-mica-beryl (Greeley,

Figure 9: (a) Shear zone cataclastics near the Platinum City adit and (b) mineralized shear zone developed at the Columbine Mine. The Columbine shear is visible above and on the left side of the adit between the two arrows. Photographs by W. Dan Hausel, 1980.

1962; Osterwald and others, 1966; Spencer, 1916).

Overall, the Esterbrook mines were small in size even though Spencer (1916) reported fairly extensive deposits. As an example, the Esterbrook Mine located in the middle of the village of Esterbrook was reported to contain massive galena shoots of up to six feet wide. This mine was developed to depths of 350 vertical feet by three shafts. However, mine dump samples show only minor galena mineralization. The deposit has limited alteration and is classified as shallow-depth epithermal (Greeley, 1962).

In the Gold Hill District of the northern Laramie Range, northwest striking chalcopyrite-gold-quartz veins in the Deep Lake Formation are restricted in size and extent. Prospect pits were developed on gossans in metagabbro and amphibolite (Houston and others, 1968).

South of the Nash Fork-Mullen Creek shear zone, northwest striking gold-copper quartz veins occur peripheral to the Keystone quartz diorite. Several thousand tons of ore have been produced in this region although only small remaining reserves are reported still in place (Curry, 1965).

Mineralized quartz veins are reported in many districts throughout the state but are too numerous to be discussed in this paper. For further discussions, the reader should refer to Hausel (1980a) and Osterwald and others (1966).

Miscellaneous Precambrian mineralization

Some Wyoming jade (nephrite) and marble are collected and mined from the Precambrian terrain each year. The jade is used as a lapidary stone, and the marble is used mainly for landscaping. Approximately 52 thousand tons of Laramie Range marble were produced in 1980 by Basins Engineering. No production records are kept for jade.

Late Precambrian and Early Paleozoic rocks contain very few recognized mineral deposits. Some simple pegmatites, formed as last crystallizing phases of granitic batholiths, were mined in the 1940's and 1950's for their feldspar content. These pegmatites are small and have limited tonnages. The most important deposits of the Early Paleozoic in Wyoming appear to be diamond-bearing kimberlite.

GEOLOGIC SETTINGS FOR PALEOZOIC MINERALIZATION

The Paleozoic geology of Wyoming that is important to recognized mineral deposits is limited to Devonian kimberlite intrusives which crop out in the Laramie-Front Range, and to Late Paleozoic carbonate and phosphorite strata exposed on the flanks of Laramide uplifts. The phosphorite beds are restricted to western Wyoming.

During much of the Paleozoic, Wyoming was a tectonically stable shelf. The periodic transgression and regression by shallow seas is recorded in the Paleozoic sedimentary record. The progressive thickening of marine sediments to the west reflects the presence of geosynclinal sedimentation in Idaho. No important mineral deposits are recognized in these early Paleozoic sediments. However, by the Devonian, a tectonic disturbance produced deep fractures that penetrated the earth's crust and tapped magma from the upper mantle. At least 90 ultramafic intrusives were emplaced along these fractures from as far north as Sybille Canyon in the central Laramie Range, to as far south as Boulder, Colorado. Several of these ultramafic intrusives, or kimberlites, contain xenoliths of predominantly carbonate Cambrian, Ordovician, and Silurian sediments. Some kimberlites, additionally are mineralized in diamond.

The Mississippian of Wyoming contains thick units of limestone exposed on the flanks of Laramide uplifts. The Madison limestone was deposited in a widespread sea and uplifted near the end of the Mississippian at which time a karst topography was developed on the exposed rock. Similar deposition of carbonates continued into the Pennsylvanian and both dolomites and high-calcium limestones were deposited.

In southeastern Wyoming, conglomerates, arkosic sandstones, marine sandstones, red shales, and some thin limestones record the development of the Ancestral Rockies uplift. Rocks of the Fountain, Tensleep, Minnelusa and Hartville formations were deposited at this time.

Deposition of sediments in the Permian was again affected by shallow seas. The depth of water increased to the west in the direction of the Cordilleran geosyncline located in Idaho. Unusual depositional conditions resulted in the formation of dark clayey shales and associated phosphatic limestone on the eastern platform of the Cordilleran geosyncline. Nearshore tidal flat sediments accumulated in central and eastern Wyoming, and these are preserved as red siltstones, shales, and sandstones, and occasional thin interbedded limestones (Blackstone, 1971).

PALEOZOIC MINERAL DEPOSITS

Although the Paleozoic rocks in Wyoming are in general, not highly mineralized, the Paleozoic does have some unique deposits. At least twelve Devonian kimberlites are diamond-bearing. Reports of additional diamonds elsewhere in the state suggest that the present boundary of the Colorado-Wyoming kimberlite province may be expanded in the future.

Limestones and dolomites are presently mined. Much of the production is for cement-rock, road metal, and decorative stone although some high-calcium limestones are produced for sugar-rock.

Uranium occurs on a karst surface developed on Mississippian limestones, and copper deposits occur in Pennsylvanian (?) and Jurassic strata in the Overthrust Belt of western Wyoming, and on the flank of the Laramie Range in southeastern Wyoming.

The Permian phosphorites of the Phosphoria Formation were formed under unusual conditions. The phosphorites are restricted to western Wyoming.

Diamond-bearing kimberlites

More than 90 kimberlite intrusives are scattered over a 120-mile north-south trending region in the Laramie-Front ranges (Figure 10). These ultramafic intrusives form a kimberlite province that extends as far north as the Sybille Canyon area of the central Laramie Range, Wyoming and as far south as Boulder, Colorado. At least twelve kimberlites are

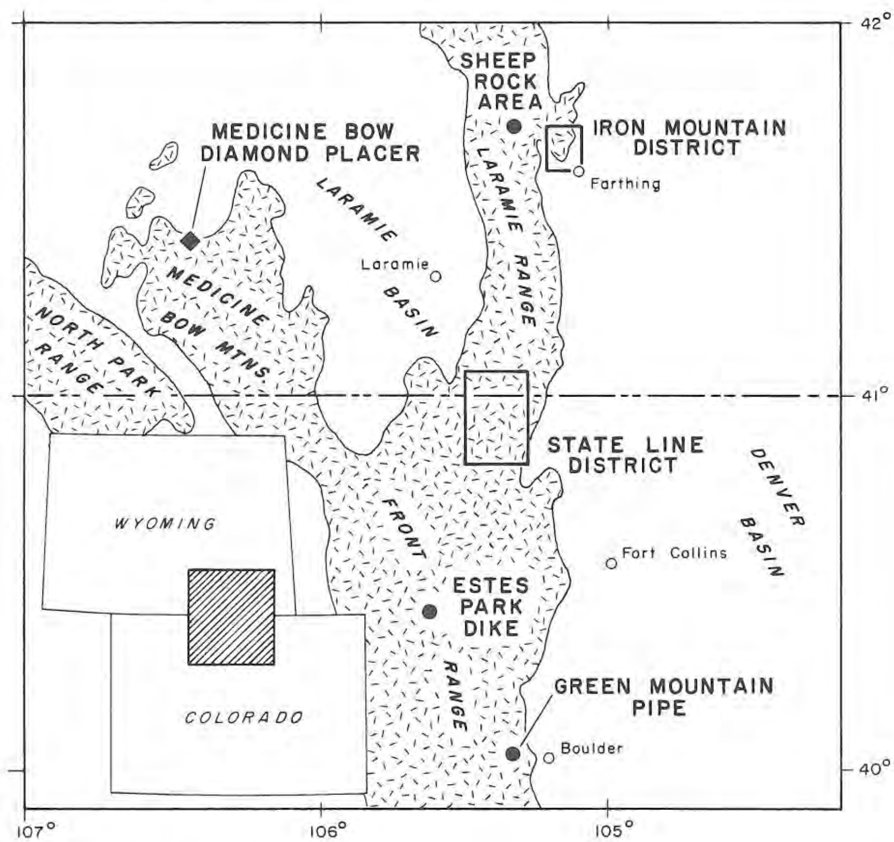


Figure 10: Location map showing known kimberlite and placer diamond occurrences. The areas are: (1) the Sheep Rock area, (2) the Iron Mountain District, (3) the State Line District, (4) the Estes Park dike, (5) the Green Mountain pipe, and (6) the Medicine Bow diamond place (Modified from Hausel and others, 1979b; and McCallum and Smith, 1978).

diamond-bearing (McCallum and others, 1977, 1979). The known kimberlites occur in five separate regions or districts.

The northernmost region, the Sheep Rock area lies 45 miles north of the Colorado-Wyoming border, and within the Laramie Anorthosite complex. Presently, a single kimberlite intrusive (less than 40 feet in diameter) crops out as massive porphyritic kimberlite (Hausel and others, 1981). This kimberlite is presently being tested for diamonds by the Geological Survey of Wyoming (Figure 11).

The Iron Mountain district (located immediately northwest of Farson, Wyoming) contains 57 kimberlite intrusives that are mainly blows (dike enlargements) and dikes indicative of feeder dike systems. Such intrusives possibly represent the erosional remnants of the plumbing systems of kimberlite pipes. These are mapped as continuous systems by the presence of bluish-gray montmorillonitic clays, residual ultramafic heavy minerals (pyrope garnet and magnesian ilmenite), rock fragments of serpentinized or carbonitized kimberlite, and vegetative and topographical differences. Most dike systems can be traced for a few feet to a few hundred feet although one dike-blow system extends nearly one mile (McCallum and Smith, 1978; McCallum and others, 1975; Smith, 1977). No diamonds have been found within this district (M.E. McCallum, pers. comm., 1979).

Because of the presence of diamondiferous kimberlite, the State Line District is of great interest to both scientific and industrial concerns. This district is named for its location straddling the Colorado-Wyoming state line.

Several studies of the State Line area kimberlites have already been published. These studies include heavy mineral prospecting (Hausel and others, 1979c; Leighton and McCallum, 1979; Mabarak, 1975); geophysics and remote sensing (Hausel and others, 1979a, 1979b, 1981; McCallum, 1974; Puckett, 1971; Puckett and others, 1972; Woodzick and others, in prep.), geology or geochemistry (Chronic and others, 1969; Eggler, 1967, 1968; Hausel and others, 1981; Hausel and McCallum, 1980; McCallum, 1979; McCallum and Eggler, 1971, 1979; McCallum and others, 1975, 1977; McCallum and Mabarak, 1976), and mineralogy and petrology (Eggler and McCallum, 1973, 1974, 1976, 1979; McCallum, 1976; McCallum and Eggler, 1968, 1971, 1976; McCallum and others, 1975, 1977, 1979; McCallum and

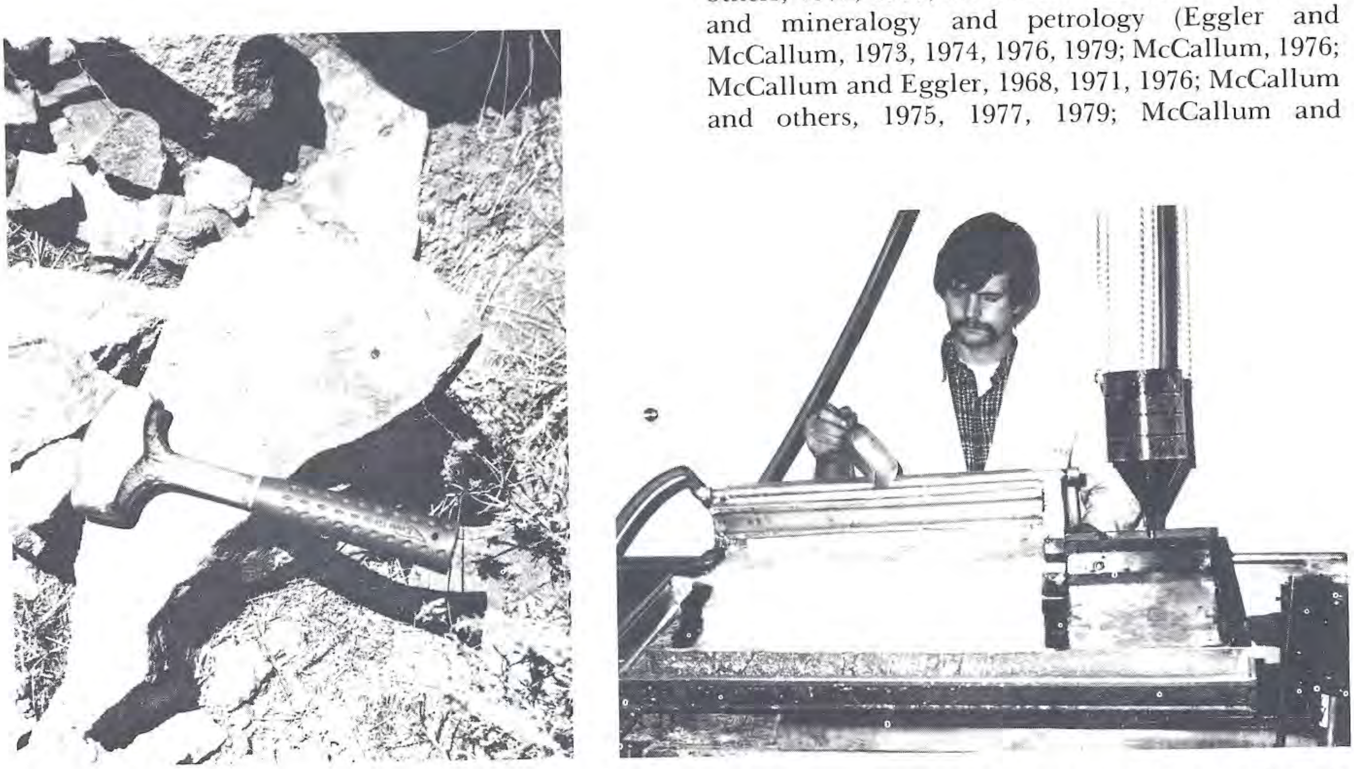


Figure 11: (a) Radichal 1 kimberlite. This is a small kimberlite intrusive that crops out in the anorthosite in the Sheep Rock area. (b) diamond testing using grease tabling methods at the Geological Survey of Wyoming. Because diamonds are notwettable, they are attracted to the grease. Photograph (a) by W. Dan Hausel, 1980, (b) by A.J. VerPloeg, 1980.

Mabarak, 1976a, 1976b; McCallum and Smith, 1978; Smith and others, 1979).

At least 35 kimberlites occur within the State Line District. The size of these kimberlites varies from a few feet wide to nearly 1,800 feet in maximum dimension for the two largest diatremes (Sloan 1, and Schaffer 13 pipes).

Several hundred to possibly a few thousand vertical feet of diamond-bearing kimberlite have been removed by erosion in this district (McCallum and Mabarak, 1976b, Figure 6, p. 7). The presence of diamond-bearing alluvial placers downstream from the kimberlites, to date, has not been examined for potential economic mineralization.

The Wyoming side of the State Line District is currently under assessment for economic diamond mineralization by Cominco American Incorporated (Hausel and McCallum, 1980). Cominco is test sampling kimberlite in the Wyoming State Line District which they refer to as the Fish Creek property. A diamond extraction testing facility is under construction in Fort Collins (Miller, 1980). Superior Minerals is conducting a similar bulk sampling program in Colorado.

The Estes Park dike, located 45 miles into Colorado, and the Green Mountain pipe, 70 miles south of the state line, are small instrusives. No diamonds are reported from these two occurrences. Of interest is a discussion by Whitaker (1898) which suggests that additional kimberlites may occur within 6 to 8 miles west of the Green Mountain pipe.

The extent of diamond-bearing kimberlite in Wyoming is not known, in that the exploration for these intrusives is still in the infant stage. Such deposits, however, can be attractive to mining companies. Of interst are placer diamonds found within the Medicine Bow Mountains (Hausel, 1977; Hausel and others, 1979a, 1979b), reported diamonds in the Sierra Madres (P.J. Graff, pers. comm., 1980), reportedly excellent stones in the Gros Ventre and northern Wind River ranges (J.D. Love, pers. comm., 1981), the occurrence of pyrope garnets and chrome diopsides in ant hills of the Green River Basin (T. McCandless, pers. comm., 1979; Hausel and others, 1979b), and the reported occurrence of similar indicator minerals south of Hart Mountain in the Bighorn Basin (J.C. Antweiler, pers. comm., 1980). Undoubtedly, more kimberlites will be discovered in the near future.

Limestone

Pennsylvanian and Mississippian limestones are important carbonate resources for a number of industrial uses. The Monolith Portland Midwest Company, in Laramie, quarries Casper Formation limestone in the western flank of the Laramie Range. The limestone from the quarry averages 90% $CaCO_3$ and is used in the manufacture of cement. Production from this quarry in 1980 totalled 382,000 tons. The quarry has operated since 1945. (Osterwald and others, 1966).

High-calcium limestone of the Casper Formation is mined by the Great Western Sugar Company on the east flank of the Laramie Range. The limestone commonly assays 97% $CaCO_3$ and is used in sugar beet factories. Presently, the company quarries rock south of Interstate 80 about 4 miles from Granite. However, up to 1978, the limestone was mined by underground methods from steeply dipping beds at the Horse Creek mine (Figure 12). The limestone at Horse Creek is mined-out, but 5 years of reserves are stored on the property. Production in 1980 from Great Western's quarry was 97,600 tons.

High-calcium limestone has also been produced for the sugar beet industry by U & I Sugar at the Fox Creek quarry in Teton County. The rock is

Figure 12: View of Great Western's Horse Creek property. While quarrying of this property began in 1912, underground methods are initiated in 1926. The limestone occurs in two steeply dipping (80°NE) massive beds that average 23 feet thick. The footwall is dolomite, and the hanging wall is hard massive red sandstone (Osterwald and others, 1966). More than four million tons of rock have been mined since 1912. Presently, five years of reserves are stored on the surface. Photograph by W. Dan Hausel, 1980.

quarried from the Amsden Formation. About 550,000 tons of rock have been quarried since 1957.

In 1980, Holly Sugar Company produced 16,000 tons of high-calcium limestone in the Torrington region. Some dolomite is produced each year for crushed rock. The major dolomite producer is the Guernsey Stone Company, which quarries dolomite in the Hartville uplift area.

Uranium

Uranium mineralization in the Little Mountain area of north-central Wyoming occurs as epigenetic deposits coating fractures and filling vugs in limestone breccias. Uranium minerals (tyuyamunite and metatyuyamunite) are additionally associated with calcite interbedded with silts and clays. The uranium is found in a karst environment developed in Mississippian Madison Limestone (Bell, 1963; Hart, 1958; Osterwald, 1965). The deposition of uranium in host Mississippian rocks is believed to have occurred during late Eocene time (Hart, 1958) although this has not been verified.

The Little Mountain district was active between 1956 to 1966 with some additional production recorded in 1970. Approximately 23,800 tons of ore were mined (Hausel, in prep.).

Copper

Copper deposits in Lincoln County occur in Pennsylvanian (?) strata. The copper is found in the Weber (Wells) quartzite north of Watercress Canyon. Similar deposits in the area are probably hosted by equivalent strata although one deposit is reported in the Beckwith Formation (Jurassic-Cretaceous) (Osterwald and others, 1966).

At the Griggs Mine on Hobble Creek, copper is found in ore shoots developed at northeasterly and northwesterly fissure intersections in the Nugget Sandstone. Assays of ore averaging 3.5% copper and 7.4 ounces of silver are reported (Allen, 1942).

Native copper, impregnated in arkose at the base of the Fountain Formation on the flanks of the Laramie Range near Tie Siding, was prospected in the early 1900's. The mineralization apparently is not extensive (Osterwald and others, 1966).

Phosphate

The Phosphoria Formation in western Wyoming contains thick accumulations of phosphorite. The phosphorite occurs as microcrystalline carbonate-fluorapatite or francolite. Common trace metals associated with the phosphorite are fluorine, uranium, selenium, and chromium (McKelvey, 1946; Sheldon, 1963).

The phosphates form major accumulations in the Overthrust Belt region, an area characterized by tight folding and thrust faulting. Many oucrops of the Phosphoria Formation in this region, however, are intensely faulted, destroying their economic value. To the east of the Overthrust Belt on the eastern flank of the Wind River Range, phosphate-bearing units of the Phosphoria Formation are less deformed, but in turn, are much tinner (Bates, 1969; King, 1947). East of the Wind River Range, the phosphate units gradually change to the carbonate rocks of the Park City Formation.

Although uranium occurs in trace amounts in many of the phosphates, Wyoming phosphates appear more enriched in uranium than similar rocks found in adjacent states. However, many of these phosphates are low-grade (in phosphate) or deeply buried.

The total phosphate resource contained in Wyoming's Phosphoria Formation is estimated at about 2.5 trillion tons, averaging 9.0% P_2O_5 and 0.0033% (33 ppm) uranium (Bauer and Dunning, 1979). More than 2 trillion tons of this resource are not considered minable with present technologic and market conditions.

From 1947 to 1978, Stauffer Chemical Company mined more than 4.6 million tons of phosphate rock, which was processed at their Leefe Plant. Presently, phosphate is not mined in Wyoming.

GEOLOGICAL SETTINGS FOR MESOZOIC MINERALIZATION

The Mesozoic rocks that are important hosts for mineralization include Triassic and Jurassic gypsiferous red bed deposits, and Cretaceous uraniferous sandstones and bentonitic units.

During the Mesozoic, deposition of strata was affected by the development of the deep north-trending geosycline in Idaho. By Mesozoic time, the geosyncline was better developed than in the Paleozoic — the seas were deeper, and widespread deposition of thick Mesozoic strata resulted. Red bed deposits were developed in eastern Wyoming in the Triassic, resulting in the deposition of thick gypsum-bearing strata of the Chugwater and Goose Egg formations. Similar red bed deposition in the Jurassic formed rocks of the Gypsum Spring Formation.

The Cretaceous included many episodes of marine transgression and regression. Extensive coal swamps are associated with these transgressive and regressive cycles, particularly in the Upper Cretaceous Frontier and Mesaverde formations. In northeastern Wyoming, thick permeable beds of sandstone in the Inyan Kara Group were deposited and provided excellent hosts for epigenetic uranium mineralization.

Volcanism to the west of the state, in response to tectonic disturbances of the Laramide orogeny, deposited thick piles of ash falls in shallow seas and lakes during the late Cretaceous. Alteration of much of the ash produced thick bentonitic strata in the Mowry, Belle Fourche, and Frontier formations.

MESOZOIC MINERAL DEPOSITS

Although Triassic and Jurassic rocks are relatively unmineralized, some gypsum is produced annually from Jurassic rocks and used as a cement additive and for the manufacture of sheet rock.

During the Cretaceous, large portions of the state were covered by shallow seas. Nearshore environments were swampy with extensive lagoons and numerous sites for peat accumulations that would later alter into coal. During the late Cretaceous, the state was blanketed by ash falls from explosive volcanic activity west of Wyoming. Many of these ash falls were deposited in shallow seas and lakes. Through alteration, many of these ash falls were converted to bentonite deposits.

Gypsum

Thick gypsiferous strata are found in Permian, Triassic, and Jurassic red beds in the state. Economically the more important gypsum beds occur in the Satanka-Forelle, Chugwater, and Gypsum Spring formations.

During 1980, Wyoming gypsum mines produced 296,100 tons of ore. Gypsum was produced from Albany, Big Horn and Park counties. In Big Horn and Park counties, gypsum was mined from Jurassic strata for use in sheet rock manufacturing, and in Albany County, gypsum was mined from Satanka-Forelle rocks and used as a cement additive at the Monolith plant. Gypsum, in Wyoming, has been mined sporadically since 1890 (Osterwald and others, 1966).

Uranium

Uranium in Crook County occurs as epigenetic mineralization in Cretaceous fluviatile sediments. The host rocks for mineralization include the Fall River and Lakota formations of the Inyan Kara Group of late Cretaceous age. Uranium mineralization is much younger than the host rocks and is believed to have been deposited 130 to 140 thousand years ago (Finch, 1967). Five different districts in Crook County produced ore.

At Elkhorn Creek, the host is the Fall River Formation. The Fall River in this district is described as a massive to thin-bedded, light-gray, fine- to medium-grained sandstone with shaley and silty lenses (MacPherson, 1956). Total uranium production from Elkhorn Creek was 28,850 tons.

The Aladdin mineralization was found localized on the western flank of an anticline. Uranium occurred in both the Fall River and Lakota formations in this district (Gray and Tennissen, 1953) Only 341 tons were shipped.

The Barlow Canyon District contains uranium ore in the Fall River Formation. Total production has amounted to more than 4,760 tons (Wilson, 1960a).

The Lakota Formation hosted ore deposits in the Carlile area (Bergendahl and others, 1961). Production from the Carlile mines totalled 72,920 tons of ore (Hausel, in prep.).

Bentonite

Ash falls, now altered and solidified, form extensive deposits of high-expanding bentonite. These bentonites are principally montmorillonite with impurities of mica, feldspar, quartz, gypsum, soluble salts, and volcanic glass shards. Several bentonite units are mined in the state. The economic beds are mainly found in the Mowry, Belle Fourche, and Frontier formations.

In outcrop, the bentonitic units are gray to yellowish in color and stand out as rounded ledges protruding from the Cretaceous shales. The apparent resistance of these bentonite ledges to erosion is the result of siliceous shales in the footwall of the bentonite. The footwall shales are enriched in silica from the leaching of the overlying bentonite (Bates, 1969; Davis, 1965).

The more important bentonites are high-swelling varieties. These have important industrial applications in the drilling mud and taconite pelletizing industries (Hausel, 1978). The high-swelling bentonites occur in areas of less than 25 to 30 feet of overburden. If the overburden is greater than 30 feet, the bentonite generally has poor-swelling characteristics (Williams and others, 1954).

In 1980, eight different companies produced bentonite from four counties (Big Horn, Crook, Natrona, and Weston). A total of 3,584,700 tons were mined.

GEOLOGIC SETTINGS FOR CENOZOIC MINERALIZATION

Geological enviroments favorable to the formation and deposition of uranium-bearing sandstone, lacustrine trona, uraniferous phosphate, oil shale, gold-bearing conglomerate, and porphyry copper-molybdenum systems occurred during the Cenozoic era.

The tectonic disturbances recorded at the beginning of the Cenozoic resulted from the continued uplift of the Rocky Mountain orogeny which began its disturbances in late Cretaceous time. The late Cretaceous seas retreated to the east as the uplift of infant ranges continued to mature. Continued uplift forced the Precambrian cores through the overlying Paleozoic and Mesozoic strata, and exposed these rocks to intense erosion. Boulder conglomerates were deposited in alluvial fans along the mountain fronts, and the adjacent basins were recipients of detrital debris fining in grain size toward the centers of intermontane basins. Fluvial environments carried large volumes of material basinward and formed thick sections of arkosic conglomerates, sandstones, and siltstones. In flood plains, finer sediments were deposited, and extensive coal swamps developed. The formation of permeable arkosic sandstones and conglomerates was important to the later deposition and concentration of extensive roll-front uranium mineralization (Houston, 1969).

The northwestern corner of the state was volcanically active by late early Eocene. Basaltic and andesitic magma poured from fractures and accumulated to tremendous thicknesses of volcanic rock forming the Absaroka Range. Ash falls were carried easterly.

To the west of Wyoming in Idaho, denudation of the Targhee uplift through the Cretaceous and into the Tertiary supplied large quantities of gold-bearing conglomerate to western Wyoming. Similar gold-bearing conglomerates were also deposited along the southern edge of the Wind River Range.

With more time, uplifting along the Laramide orogeny lessened and a number of intermontane lakes filled broad basins. Lake Gosuite, in the Green River Basin, precipitated numerous beds of trona, uraniferous phosphate, and oil shale. The greatest trona reserves in the world were deposited at this time.

Volcanism increased in activity with volcanic centers erupting in the Rattlesnake Hills of central Wyoming and intrusive activity in the Black Hills of northeastern Wyoming. By mid-Tertiary, mineralized granodiorite stocks intruded the Absaroka volcanics. Near the end of the Tertiary, detrital sedimentation was much less intense. Volcanism in the Absarokas as well as new activity in the Leucite Hills in southwestern Wyoming and at Battle Mountain in south-central Wyoming added volcanic debris to the sediments.

CENOZOIC MINERAL DEPOSITS

Undoubtedly, the more important Cenozoic mineral deposits include epigenetic uranium deposits in arkosic sediments and trona deposits in lacustrine sediments. Uranium was first mined between 1918 to 1922 in small tonnages at the Silver Cliff Mine in east-central Wyoming. However, in the early 1950's, several major uranium discoveries were made in Tertiary sediments and led to the development of Wyoming's uranium mining industry (Wilson, 1960a) (Figure 13).

Several other Cenozoic deposits that may become economically important in the future include porphyry copper mineralization, gold-bearing conglomerates, and zeolites. Some sand, gravel, and construction materials are mined each year.

Figure 13: The historic Alma 8 (Uranium Box) mine and rod mill, one of the first uranium mines in the state located in the Pumpkin Buttes region of the Powder River Basin. The first economic uranium deposits found in the state in Tertiary sediments were discovered by J.D. Love of the U.S. Geological Survey. His discovery led to many additional discoveries in nearby basins. Photograph by W. Dan Hausel, 1978.

Uranium

The major economic uranium deposits are hosted by Eocene arkosic sediments of the Wind River, Wasatch, and Battle Spring formations. Mineralization dominantly occurs as epigenetic stratabound roll-front deposits located at oxidized (altered)-reduced (unaltered) host rock contacts (Figure 14). The majority of the host rocks are fluviatile or are fluvial-fan type facies. Total uranium production in 1980 amounted to approximately 5,472,000 tons of ore.

Economic mineralization in the Gas Hills district is restricted to the Puddle Springs Member of the Wind River Formation. The Puddle Springs is between 300 to 800 feet thick within the district, and is comprised of coarse-grained arkosic sandstones and conglomerate with interbedded mudstone, carbonaceous shale, and siltstone units. More than 23,000,000 tons of uranium ore have been mined from the Gas Hills district since mining first began in 1954 (Hausel, 1980c; Hausel, in prep.; Snow, 1978).

Commercial uranium deposits in the Powder River Basin occur almost exclusively within arkosic sediments of the Wasatch Formation. The reduction-oxidation boundaries at roll-fronts are more distinct in the Powder River Basin than in the Gas Hills or Shirley Basin districts. Oxidation of the host fluvical sediments is apparent as a distinct reddish coloration due to the replacement of pyrite by hematite. The unaltered sandstone remains light-tan to gray (Dahl and Hagmaier, 1976). Total uranium production from the Powder River Basin amounts to more than 9 million tons of ore to date (Hausel, in prep.) (Figure 15).

Uranium deposits in the Shirley Basin District are hosted by the Wind River Formation. At least two, and possibly three alteration fronts are recognized near the base of the Wind River. The ore lies under 100 to 450 feet of overburden. The alteration, which is not very distinctive, is seen as a subtle color change from an unaltered gray-colored sandstone to an altered greenish-yellow colored sand. The primary ore mineral, uraninite, fills pore spaces, coats sand grains, and replaces

Figure 14: Exposed uranium roll-front in wall of Pathfinder Mines Corporation's Shirley Basin Mine. The roll-front forms the black concentric feature in the center of the photo. Photograph by W. Dan Hausel, 1977.

Figure 15: Uranium mines in the southern Powder River Basin. (a) Open pit mining at Exxon's Highland Mine and (b) headframe of Kerr-McGee's Bill Smith Shaft. Photographs by W. Dan Hausel, 1979.

disseminated organic matter (Harshman, 1968, 1972). The alteration reflects the removal of pyrite, calcite, and decomposed carbonaceous material and the formation of high-iron clays (Melin, 1969).

Mineralization at the inactive Baggs district lies in a unique setting. Uranium occurs in Miocene sandstones of the Browns Park Formation. The Browns Park consists of a series of eolian, soft, friable, highly cross-bedded sands. Approximately one-third of the district's ore occurs as oxidized bodies of autunite, uranophane, and schroeckingerite. At depth, uranium occurs as a species in the phosphouranylite family and as a uranium-titanium phase (Collyer, 1979).

Approximately 176,000 tons of uranium ore were mined from 1954 to 1967 in the Baggs District. The most recent reported activity in the district was exploration by Urangeshellschaft USA. They outlined potential reserves of 8 to 15 million pounds of yellowcake (Collyer, 1979).

At Copper Mountain, uranium occurs in both Precambrian and overlying Tertiary sediments. Mineralization occurs in arkosic sediments of the Teepee Trail Formation and is associated with propylitically altered rocks and breccia zones and along fractures of reverse faults in the underlying Precambrian (Yellich and others, 1978). Rocky Mountain Energy Company recently explored this region, but decided that the resource was marginal when prices began to drop.

The Crooks Gap District is undoubtedly the most structurally complex of the Wyoming uranium mining regions. The uranium is found coating fractures and fault gouge of exposed faults in Cambrian shales in the northeast portion of the district, and occurs as irregular sinuous roll-fronts in the lower 1,500 feet of the Battle Spring Formation (Stephens, 1964). The Battle Spring consists of a fluviatile-deltaic depositional environment with rapid permeability changes over short distances both laterally and vertically. The arkosic sediments vary from mudstones and siltstones to sandstones and boulder conglomerates (Files, 1972).

Surface alteration is recognized by pink- to pinkish-brown staining of altered sediments in contrast to the unaltered drab white to tan color (Harshman and Adams, 1981). Below the zone of oxidation, the alteration is difficult to recognize. The altered rock is bleached white compared to the drab white or tan color of the unaltered sandstone (Bailey, 1969). More than 4,800,000 tons of uranium ore have been mined from the Crooks Gap's mines from 1954 to present. Uranium in the Great Divide Basin (Sweetwater Mine) occurs within a fluvial-fan complex of the Battle Spring Formation (Sherborne and others, 1979).

Trona, uraniferous phosphate, and oil shale

Beds of trona, uraniferous phosphate, and oil shale were deposited in lacustrine sediments of the Green River Basin. The trona beds are found in the Wilkins Peak Member of the Green River

Formation. At least 42 beds occur over a 1,300 square mile region (Culbertson, 1969).

The Wilkins Peak Member consists of beds of marlstone, claystone, limestone, tuff, mudstone, siltstone, sandstone, trona-halite, 77 persistant beds of oil shale, 42 beds of trona (25 of which are persistent and thick), and 18 uraniferous phosphate zones (Burnside and Culbertson, 1979; Love, 1964).

The 25 thick trona beds are estimated to contain a total of 81.7 billion tons of trona and 52.7 billion tons of mixed trona and halite, or a total resource of 134.4 billion tons (Burnside and Culbertson, 1979).

The first trona was mined in 1946 from a 1,500-foot shaft developed by Westvaco (now known as FMC Corporation) (Burnside and Culbertson, 1979). More than 100 million tons of trona have now been extracted since mining began in 1946. The ore is mined from four underground mines (with a fifth mine under construction) predominantly by room-and-pillar methods (Hausel, 1978).

Gold-bearing conglomerates

Extensive auriferous conglomerates occur in the Dickie Springs-Oregon Gulch area, south of the Wind River Range, and in the general vicinity of Jackson Hole and the Teton Range of northwestern Wyoming.

In the Dickie Springs-Oregon Gulch area, gold is found finely disseminated in boulder conglomerates of the Wasatch Formation and in nearby Recent placers. The host rock contains giant boulders (as large as 25 feet in diameter) in an arkosic matrix. The conglomerates are believed to be derived from a grantitic source in the Wind River Range from a region other than the South Pass-Atlantic City area. An estimated gold resource in excess of 28,500,000 ounces is believed to occur in these conglomerates (Love and others, 1978).

The gold-bearing conglomerates in northwestern Wyoming occur in several formations, and are discussed by Antweiler and others (1977), Antweiler and Love, (1967); Lindsey (1972); and Love (1973).

Placer gold occurs in modern alluvial stream and terrace deposits as well as in quartzite conglomerates of Tertiary and Cretaceous age in northwestern Wyoming. It is estimated that the Snake River gravels contain at least 100 million ounces of gold (Antweiler and Love, 1967) and that the Pass Peak Formation, which is only one of several gold-bearing sedimentary formations in northwestern Wyoming, contains more than 46 million ounces of gold (Antweiler and others, 1977).

Zeolites

Zeolites in potentially minable quantities occur in the Beaver Rim region of Fremont County and in the Washakie Basin of Sweetwater County. The zeolites in the Washakie Basin represent some of the more extensive deposits found in the United States (Figure 16).

On rocky Mountain Energy Company's property in the Washakie Basin, zeolite occurs as light-green clinoptilolite, and is located under thin overburden in an area that extends for several miles (Surdam, 1980).

Precious and base metal, fluorite, and rare earth deposits associated with alkalic intrusives

Crook County, in northeastern Wyoming, contains contact metasomatic replacement mineralization near alkalic intrusive complexes, and some placer and vein deposits. Mineralization includes fluorite, rare earths, gold, silver, lead, and zinc (Hausel, 1980a; Osterwald and others, 1966; Welch, 1974). Three districts in the county — Bear Lodge, Black Buttes, and Negro Hill-Mineral Hill have

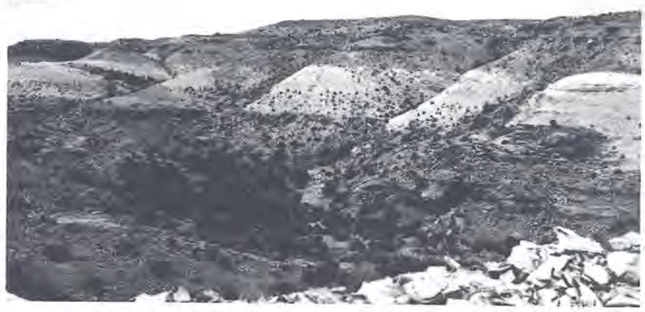


Figure 16: Bedded zeolite deposits in the Washakie Basin occur in the Adobe Town Member of the Washakie Formation (Roehler, 1973). The Zeolite units are the light gray, bedded units in the photograph. Photograph by W. Dan Hausel, 1980.

produced only minor ore tonnages in the past, and presently contain no active mines or prospects.

In the Bear Lodge Mountains, fluorite deposits are found in mineralized limestone at the contact between the Tertiary alkalic intrusives and metamorphosed limestone. Rare earths occur in iron-manganese fracture-filling veins and in zones of intensely altered igneous rock. Average fluorite assays show 36% CaF_2 although essays as high as 90% CaF_2 and rare earth oxide contents as high as 12.99% are reported (Osterwald and others, 1966).

Mineralization at Black Buttes is restricted to small replacement bodies in limestone. Lead, silver, and zinc reportedly replace Paleozoic limestone and fill breccias. An assay produced 2 ounces of silver and 5.7% zinc (Osterwald and others, 1966).

In the Negro Hill-Minerl Hill region, gold is the most important type of mineralization although some tin is reported in placers and pegmatites. An estimated 9,350 ounces of gold were produced from placers prior to 1893 in the Negro Hill-Mineral Hill district (Hausel, 1980a). Lode deposits occur as quartz veins and mineralized feldspathic breccia and diorite (Welch, 1974).

Copper-molybdenum porphyry deposits

Several copper-molybdenum porphyry systems intrude thick volcanic sequences of the Absaroka Mountains in northwestern Wyoming. The intruded rocks consist of more than 5,000 feet of layered volcanic rocks which include laharic breccias, lava flows, flow breccias, and tuffs.

By late Eocene (?) to early Oligiocene (?), these flows were intruded by numerous dikes and felsic stocks. The stocks apparently line up along a northwest-southeast trend which is projected southeast through the southern Rocky Mountain orogeny (Fisher, 1972; Rouse, 1940) and northwest through Butte and the Rocky Mountain trench (Hollister, 1978). Similar alignments of porphyry systems are reported in Mexico, Arizona, and Nevada (Hollister, 1978; Lowell, 1974; Roberts, 1966) and may represent zones of weakness that extend to lower crustal depths.

The more important intrusive phases in the Absarokas are composite stocks that exhibit stockwork, vein, disseminated mineralization, and alteration similar to the porphyry copper deposits of Hollister (1978); Lowell and Guilbert (1970); and Creasey (1966).

On a district scale, faults, joints, and fissure zones in the Absarokas trend roughly north-south (Table 1). In many places, the north-south trends are intersected by east-west fractures at the site of the mineralized intrusive (Fisher, 1972; Wilson, 1964).

In the respective mineralized areas (Figure 17), the intruding rock closest to the ore is a composite intrusive of granodiorite composition and represents more than one phase of intrusive activity. Mineralization occurs as disseminated copper-molybdenum enclosed within the intrusive rock. Disseminated ore minerals occur as chalcopyrite, pyrite, and molybdenite; and minor bornite is reported in some areas.

Narrow quartz veinlets containing molybdenite, chalcopyrite, and pyrite, occur throughout the disseminated mineralized intrusives. Steeply dipping veins extend from the intrusive bodies into the country rocks. These contain quartz, siderite, ankerite, calcite, barite, and dolomite gangue with argeniferous galena, chalcopyrite, sphalerite, pyrite, tetrahedrite, and additional minor sulfides. Very little alteration is associated with the veins.

Leaching and oxidation at the surface is not extensive in any of the districts because of the rapid rate of erosion. Zones of oxidation are represented by weak gossans containing boxworks, limonite, jarosite, and minor amounts of malachite, azurite, and molybdite.

Enrichment has not been important; however, in the Stinkingwater District, Fisher (1972) reports that a zone of supergene enrichment with a maximum thickness of 200 feet or greater was penetrated by drilling. Chalcocite is the most common replacement mineral in the supergene enriched zone.

Alteration of the host intrusive and surrounding country rocks was followed by hydrothermal activity. The surrounding country rocks show signs of propylitic deuteric alteration (Nowell, 1971). Near the intrusive centers, alteration becomes more intense and the rocks are hydrothermally altered. Major alteration products developed in the outer hydrothermal propylitic zone are quartz, calcite, epidote, and montmorillonite with minor pyrite and chlorite.

A phyllic zone of alteration grades from the propylitic altered rock towards the intrusive. The alteration zone is represented by quartz, sericite, and pyrite. All of the districts contain some form of recognizable phyllic alteration with the exception of the Sunlight region. A very limited and intense

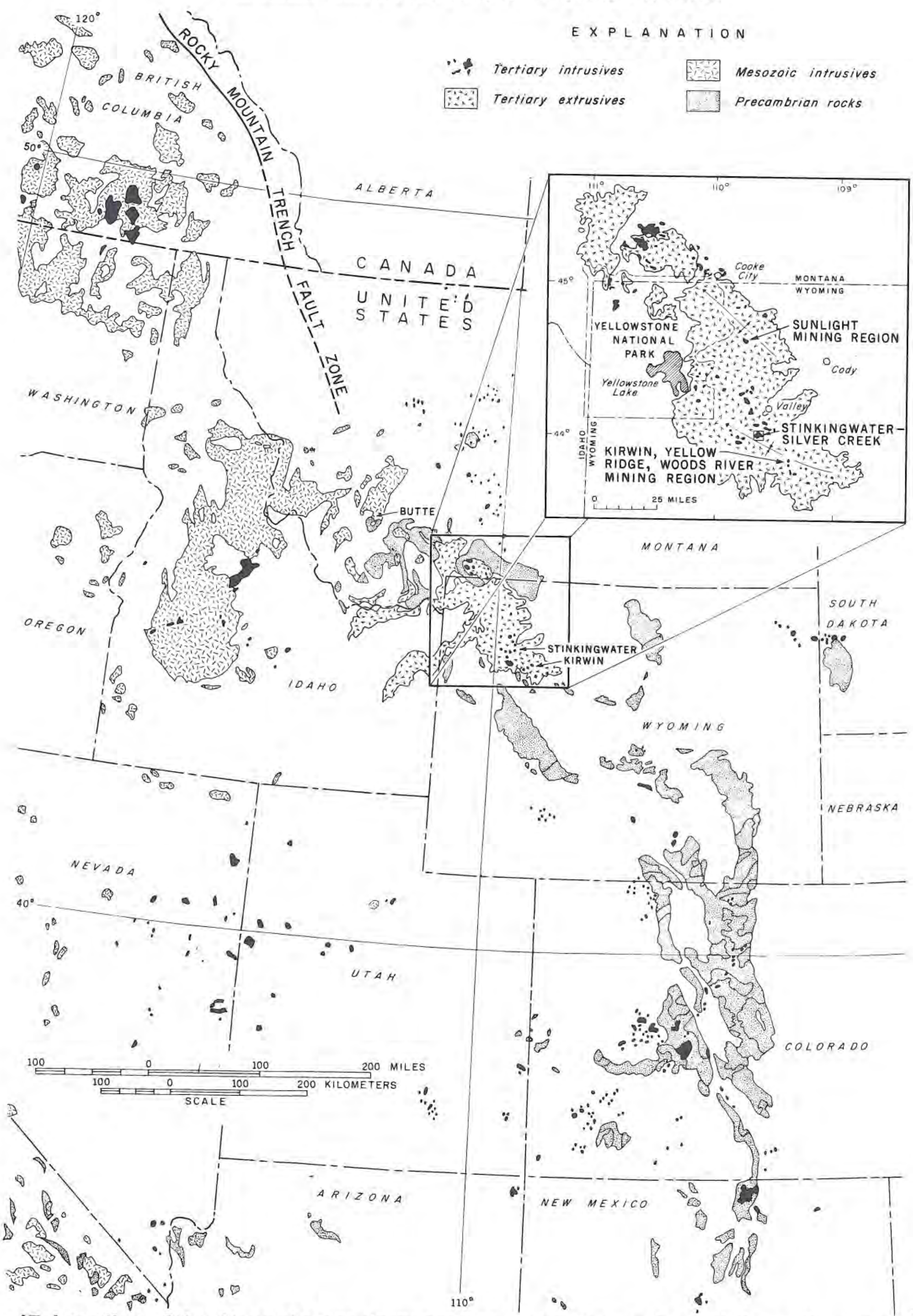


Figure 17: Location of the Absaroka porphyry copper-molybdenum deposits in northwestern Wyoming. The porphyry centers tend to align with the southern Rocky Mountain orogeny and the Rocky Mountain trench, Fisher (1972); Hollister (1978); and Rouse (1940).

TABLE 1: Some characteristics of the Absaroka porphyry copper deposits

District or Region	Intrusion close to ore	Rock Intruded	Structural Trends	Alteration zones present	Supergene enriched zones
KIRWIN	Bald Mtn. grandiorite (Wilson, 1960; 1964)	Wiggins Fm. (andesites) (Wilson, 1964)	Northwesterly & northeasterly striking joints and fissures (Wilson, 1964)	propylitic phyllic potassic argillic (?) (Nowell, 1971)	None (Wilson, 1964)
MEADOW CREEK	Meadow Creek granodiorite (Wilson, 1975)	Wiggins Fm. (andesites) (Wilson, 1975)	Intersected by north trending and east-west trending faults (Wilson, 1975)	propylitic phyllic (Wilson, 1975)	None (Wilson, 1975)
YELLOW RIDGE	Granodiorite, andesite porphy- & hornblende andesite (Fischer et al., 1977)	Wiggins Fm. (andesites) (Fischer et al., 1977)	—	propylitic phyllic potassic (Fischer et al., 1977)	—
SILVER CREEK	Dacite porphyry, rhyodacite porphyry (Fischer et al., 1977)	Wapiti Fm. Wiggins Fm. Trout Peak Trachyandesite (Fischer et al., 1977)	Well developed fractures trend from N 35° E to N 80° W (Fischer et al., 1977)	propylitic phyllic potassic (Fischer et al., 1977)	—
STINKINGWATER	Needle Mtn. granodiorite, Crater Mtn. dacite (Fischer, 1972)	Trout Peak Trachyandesite & Wiggins Fm. (Fischer, 1972)	Northwest and east to northeast fracture sets (Fischer, 1972)	propylitic phyllic potassic argillic (Fischer, 1972)	Present; maximum thickness at least 200 feet (Fischer, 1972)
SUNLIGHT	Syenite (Dreier, 1967; Rich, 1974)	Wapiti Fm. (Nelson & Prostka, 1980)	Dominant set of fractures trend N 39° W (Dreier, 1967)	propylitic potassic (Dreier, 1967; Rich, 1974)	—

potassic alteration zoné is reported in all of the mineralized regions except for the Meadow Creek area. The potassic zone is usually bleached and contains secondary orthoclase, biotite and quartz.

Argillic zones are not well defined and are only hinted at in the Stinkingwater (Fisher, 1972) and in the Kirwin (Nowell, 1971) mineralized areas.

All these mineralized areas of porphyry copper-molybdenite mineralization in general, either lie within or immediately adjacent to wilderness regions. Although they may represent a possible economic source of base and precious metals, the present soft base metal market and the restrictive laws and environmental regulations that apply to mining in and around wilderness regions may preclude the exploitation of these deposits, indefinitely. Many of these mineralized regions were prospected in the late 1800's and early 1900's, with renewed interest in the 1970's. Recently, the U.S. Bureau of Mines (Rosenkranz and others, 1979) reported that the Kirwin area contained a resource of 63.5 million metric tons of 0.75 weight percent copper and 0.015 weight percent molybdenum. Exploration for composite felsic intrusions in the Absaroka region may reveal additional porphyry mineralized intrusives.

Sand, gravel, and construction materials.

Sand, gravel, and other construction materials are produced in significant tonnages each year in the state (Figure 18). In 1980 Morrison-Knudsen and Union Pacific Railroad mined 1,572,100 tons of granite ballast from quarries in the Sherman Granite of the southern Laramie Range. The ballast was used for railroad bedding. Sand and gravel production, statewide, totalled 5,043,300 tons. Scoria mined from above burned-out coal beds in the Powder River Basin totalled 33,100 tons and scoria used as railroad ballast by Burlington Northern totalled 74,900 tons.

Figure 18: Sand and gravel operations along the Laramie River near Laramie. Each year the sand and gravel industry produces 4 to 5 million tons of material. Photograph by W. Dan Hausel, 1977.

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