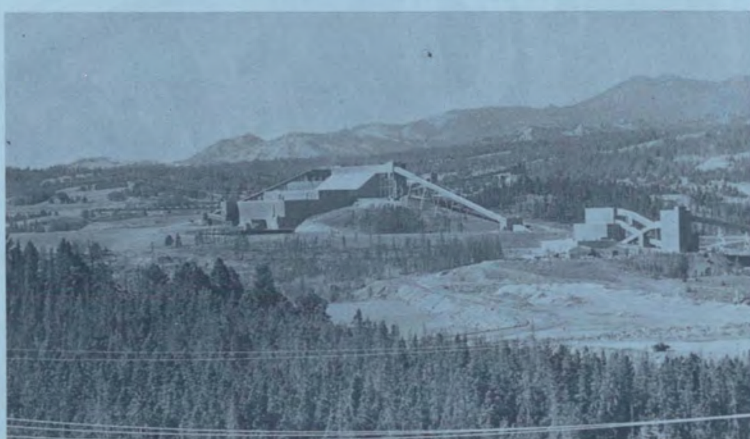
THE GEOLOGICAL SURVEY OF WYOMING

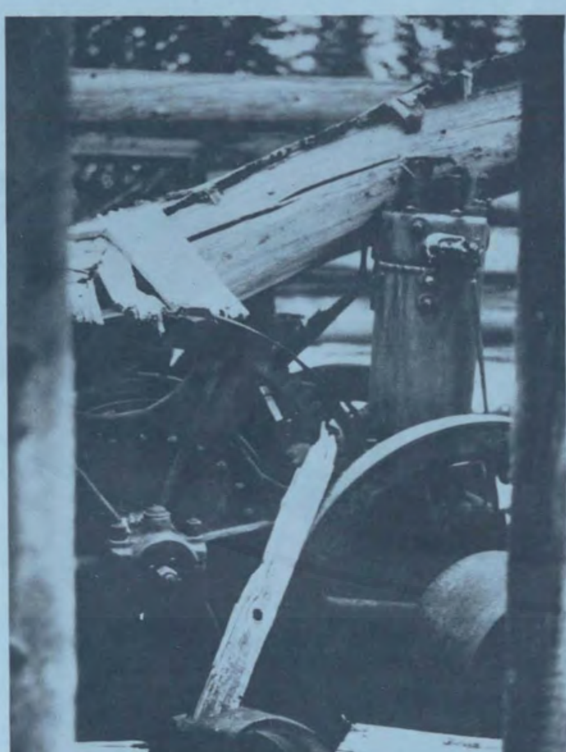
Gary B. Glass, State Geologist

PRELIMINARY REPORT No. 19

ORE DEPOSITS OF WYOMING

by W. Dan Hausel





LARAMIE, WYOMING

1982

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Front cover. Upper left, U.S. Steel Corporation's Atlantic City taconite (iron ore) mill and mine, located on the South Pass greenstone belt. Upper right, Western Nuclear's Golden Goose uranium shaft at Crooks Gap. Lower right, view of B&H gold mine, looking south, with Oregon Buttes on the horizon. The B&H is in the South Pass greenstone belt. Lower left, remains of copper activity, early 1900's, in the southern Sierra Madre. Photographs by W. Dan Hausel.

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"Of gold we have enough to place in every hand a Solomon's temple, with its vessels.

"Copper? Why, the Grand Encampment region alone could draw enough wire and our water power generate enough electricity with which to electrocute the world and to make the universe throb with magnetism.

"Iron? We have mountains of it. At Guernsey and Rawlins are found the finest and most extensive deposits of Bessemer steel ores in the world. At Hartville it is shoveled into cars with a steam shovel at a cost of 3 cents per ton. If it were necessary to put a prop under this hemisphere to keep it in place Wyoming could do it with a pyramid of iron and steel."

The Hon. Fenimore Chatterton
Wyoming Secretary of State
December, 1901
Wyoming Industrial Convention

LARAMIE, WYOMING
1982

ABSTRACT

Wyoming is one of the richest mining states in the United States. The state is endowed in a variety of mineral deposits found in fairly unique host geological settings as compared to those in the other western states. Extensive bedded trona and bentonite, and fissionable and fossil fuel deposits, represent Wyoming's important economic commodities. Of potential interest are a number of base, precious, ferrous, ferroalloy, industrial, and construction minerals, metals, and rocks. Of these groups several are present as subeconomic mineralization and a few as important economic deposits.

The Precambrian of Wyoming hosts both syngenetic and epigenetic deposits. Some of the more important recognized deposits include iron formations and lode gold in Archean greenstone belt successions exposed in Laramide uplifts. Many of the state's Proterozoic deposits lie in southeastern Wyoming, and these rocks include iron formations (both Archean and Proterozoic) and placer uranium in supracrustal geosynclinal metasedimentary successions, syngenetic and epigenetic base metals in volcanogenic schists, epigenetic base and precious metals in shear zone cataclastics, and industrial minerals from anorthosite and pegmatite hosts.

Although the Paleozoic rocks in Wyoming are, in general, not highly mineralized, the Paleozoic does have some unique deposits. At least twelve Devonian ultrabasic kimberlite pipes in the Laramie Range are diamond bearing. Late Paleozoic limestones and dolomites on the flanks of Laramide uplifts provide important industrial and construction materials. The Permian phosphorites of the Phosphoria Formation in western Wyoming represent a tremendous resource of phosphate and a host of associated metals.

Although Triassic and Jurassic rocks are relatively unmineralized, some red bed gypsum is quarried as a cement additive and for sheetrock, and some red bed copper deposits in the Overthrust Belt are of potential interest. Cretaceous sediments contain some strata-bound epigenetic uranium in the Black Hills and also extensive layers of bentonite exposed on the flanks of most Wyoming ranges.

Undoubtedly, the most important Cenozoic deposits include epigenetic strata-bound uranium in arkosic sediments in broad Tertiary basins and trona deposits in lacustrine sediments in the Green River Basin of southwestern Wyoming. Other Cenozoic deposits that represent important resources include porphyry copper-molybdenum deposits in the Absarokas, auriferous conglomerates, and some bedded zeolite. Some sand, gravel, and crushed rock are mined each year.

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FOREWORD

This paper is based primarily on published and unpublished reports on numerous mineral properties in the State, and on my own field observations for the Geological Survey of Wyoming. In areas where very little information was available, I attempted to visit, and to at least make a cursory examination; and, when the time permitted, to map the deposits and associated rocks.

I am greatly indebted to the many geologists and prospectors who contributed thoughts and ideas for this manuscript. In particular, special thanks go to Gary B. Glass and Robert S. Houston, who reviewed an abstracted version of this paper which was presented to the 1981 Wyoming Geological Association field conference in Jackson, Wyoming, and to David Copeland, who edited this manuscript. E.J. "Woody" Renner of the Wyoming Ad Valorem Tax Division was most helpful in providing many of the production statistics.

Additionally, I appreciate the many thoughts and ideas garnered in conversations with M.E. McCallum and C.D. Mabarak relating to kimberlites, with P.J. Graff and T.L. Klein relating to base metals and greenstone belts, and with J.D. Love relating to a great variety of deposits.

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Geological Survey of Wyoming

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 being stamped in several districts (Figure 1). Most notable was the Sweetwater District in the South Pass area.

Significant production of base metals began in 1899 with the development of copper deposits 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 the 20th, 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 been surpassed only by exploration for oil and gas. The 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, coal, high-swelling bentonite, carbonates, anhydrite, phosphate, iron formations, and sand, gravel, and other construction materials have also become important commodities in the state. With favorable market conditions, these deposits will continue to be mined in significant amounts.

During the last fifty years, base and precious metals have been notably absent from production statistics. Favorable geologic settings coupled with more favorable markets may lead to renewed exploration for and development of these metals.

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

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

The major nonmetal and fissionable metal deposits for which the state is well known occur in detrital 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 below 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 greenstone belts and (2) a basement of Middle Proterozoic (1.9 to 1.6 b.y.) volcanogenic schists. The two basements, or provinces, meet in southeastern Wyoming and are separated by the Mullen Creek-Nash Fork shear zone (Houston and McCallum, 1961; Houston and others, 1968). The older Archean terrain is termed the Wyoming province (Engel, 1963; Houston and Karlstrom, 1979) (Figure 2).

The Archean rocks of the Wyoming province consist of relatively unmineralized gneisses, mig-

A

B

C

Figure 1. Remains of the early gold mining history of Wyoming. (A) Gold ore stamps, (B) rock crusher, and (C) stamp mill are located in the Centennial Ridge area. Photographs by W. Dan Hausel, 1980.

matites, 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 a 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 and argillaceous metasediments which in turn are overlain by a predominately arenaceous metasedimentary group. Structurally, the greenstone belts have been folded, fractured, and intruded by granitic magmas and metamorphosed to amphibolite and greenschist facies. In their simplest form, greenstone belts are linear in plan and form deep synclinal basins in cross section. Favorable hosts for mineralization include quartz veins, mafic-felsic volcanic contacts, and some metasediments (Windley, 1979). Several examples of greenstone belt-type terrains are found in Wyoming (Figure 2).

The edge of the Wyoming province, in southeastern Wyoming immediately north of the Mullen Creek-Nash Fork 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

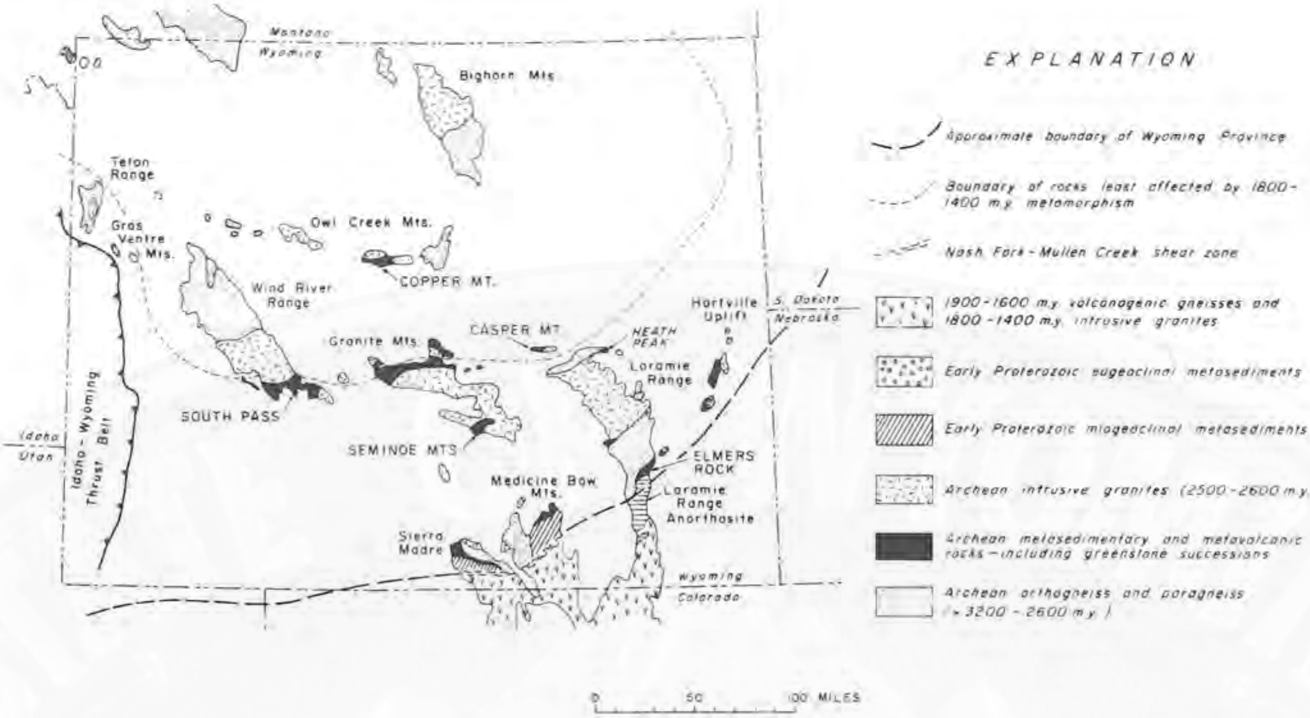


Figure 2. Location map of the Wyoming greenstone belts: the South Pass (Bayley and others, 1973; Hausel, 1980a), Copper Mountain (Duhling, 1971; Gliozzi, 1967; Granath, 1975; Hausel, 1981a; Houston, 1973), Granite Mountains (Houston, 1973; Love, 1970; Peterman and Hildreth, 1978), Seminoe Mountains (Bayley, 1968; Bishop, 1964), Casper Mountain (Beckwith, 1939; Hausel and Glass, 1980), Elmers Rock (Graff and others, 1981, 1982), two small belts in the central and northern Laramie Range, and belts in the Medicine Bow and Sierra Madre Mountains (Karlstrom and others, 1981). After Condie (1976), Houston and Karlstrom (1979), and Karlstrom and others (1981).

and Medicine Bow Mountains, the metamorphics are more typical of miogeosynclinal sedimentation.

Three successions of metasediments are recognized in the Sierra Madre and Medicine Bows. 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 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). These metasediments, described as Proterozoic by Houston and Karlstrom (1979), may be Archean in age (Snyder, 1980). The most important recognized mineralization in the Hartville metasediments, to date, is iron formation.

South of the Mullen Creek-Nash Fork shear zone, in the southern Sierra Madre, Medicine Bow, and Laramie ranges, is a series of eugeosynclinal Middle Proterozoic (1.9 to 1.6 b.y.) metamorphics that apparently 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).

These metamorphics in the southern Sierra Madre form a series of calc-alkaline volcanics that are 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 postdepositional granitic intrusives (Divis, 1976, 1977). The rocks have several important similarities with rocks of the Canadian Superior

Province where strata-bound 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 rocks of the Wyoming Province prior to the deposition of the Proterozoic metasediments in southeastern Wyoming (Tweto, 1968). 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 Mullen Creek-Nash Fork shear zone divides 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 can be 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.

About 1.5 b.y. ago, the Mullen Creek-Nash Fork 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 titaniferous magnetite (magnetite-ilmenite).

Approximately 1.4 b.y. ago, southern Wyoming was intruded by granitic magmas. The Sherman Granite in the southern Laramie Range, and southeastern Medicine Bow Mountains was emplaced at that time (Peterman and others, 1968).

PRECAMBRIAN MINERAL DEPOSITS

A number of syngenetic and epigenetic 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 has been 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, anorthosite, and some Archean and Proterozoic pegmatite deposits.

GREENSTONE BELT MINERALIZATION

Greenstone belts throughout the world are known for their important resources of precious, base, iron, ferroalloy and industrial metals (Fripp, 1976a; Watson, 1976; Windley, 1979). The most important recognized greenstone belt mineralization in Wyoming includes iron formation and lode gold although a number of other minerals have been reported from several belts.

The Wyoming greenstones do contain some important types of mineralization, but, generally, the Wyoming greenstones do not appear to be as endowed as greenstones in Canada, southern Africa and Australia. This may be due to limited exposures of greenstone terrain (e.g., some extensive greenstones in Canada occur in linear belts over 600 miles long), and to lack of differentiation in the volcanic series.

At Copper Mountain (Figure 2), the rocks that form the greenstone have been isoclinally folded, intruded by granites, and metamorphosed to amphibolite grade. Most of this belt consists of a fuchsitic quartzite and quartz-rich gneiss lower unit overlain by pelitic schists, iron formation, amphibolite schists, biotite garnet schists, chert, and marble. Recognized mineralization includes (1) iron formation, (2) fissure-filling quartz veins containing gold, scheelite, chalcopyrite, argentiferous(?) galena, metallic bismuth(?), and pyrite, and (3) lepidolite and feldspar associated with pegmatites.

The iron formations are considered to be subeconomic. These units occur near the crest of the Owl Creek Mountains and extend east for nearly 10 miles. In general, the iron formation consists of magnetite and quartz with minor pyroxene, amphibole, tremolite, and garnet. At some localities, such as at the McGraw Mine, copper occurs as spotty disseminations in quartz veins that cut the iron formation (Harrer, 1966). In places, the thickness of the iron formation varies from a few feet to a few hundred feet (Gliozzi, 1967; Harrer, 1966; Millgate and Gliozzi, 1966). Average iron content of these rocks is about 32 percent Fe. A characteristic sample of iron formation collected from the McGraw property (sec. 7, T.40N., R.92W.) assayed 33.7 percent Fe, 45.6 percent SiO_2, and 0.25 percent Cu (Harrer, 1966). No gold

Figure 3. View of the Gold Nugget stamp mill. In addition to the South Pass, several greenstones were prospected for lode gold, such as the Gold Nugget camp in the Copper Mountain area. There, gold mineralization occurred in quartz veins hosted by amphibolite schists. Mined tonnages were small, and the amount of stamped ore was limited (Hausel, 1981a). Photograph by W.D.H., 1981.

assays are reported for the iron formation.

The only known gold mines reported within the Copper Mountain greenstone belt occur within, and in the near vicinity of, the Gold Nugget camp (T.40N., R.94W.) near Birdseye Pass (Figure 3). This camp was developed in the 1930's by several small prospect pits, open cuts, shafts, and adits, none of which contained extensive workings. Although a gold-quartz stamp mill was constructed on the property, the Gold Nugget camp never really was developed beyond the prospecting stage. The stamp mill showed limited signs of activity, if any, in that no waste rock or tailings were found within the perimeter of the mill during field reconnaissance. The mines that were examined had very small dumps that indicated limited mining activity in the camp.

The ore occurred as auriferous quartz veins in amphibolite schist near its contact with granite. The quartz veins generally are small, and range from stringers to about one foot thick. Mineralization was reported to occur as "free milling" gold associated with limonite stains and boxworks, and as gold disseminated in sulfides (Bregy, 1935). Primary sulfides are pyrite and chalcopyrite. The quartz veins are black to dark gray, and fill fractures and fissures in the host schists. Alteration associated with the veins includes chloritization and silicification localized immediately adjacent to the vein (Hausel, 1981a).

The tenor of the deposits was reported to range from a trace to as high as 2.4 ounces in gold per ton. Old mine reports suggest that the Gold Nugget claims contained a reserve of 30,000 tons of gold ore averaging 0.41 ounces per ton, but the vein was limited in extent by faulting along the schist-granite contact (Bregy, 1935). Recent assays of selected grab samples of dump material are not consistent with the reported assays. The richest assay of four high-graded grab samples was only 0.02 ounces per ton. (Hausel, 1981a).

The only major copper deposit in the district is the DePass lode. At the DePass (Williams-Luman) Mine (sec. 14, T.40N., R.92W.), fractured quartz veins form ore shoots where they intersect in schist country rock near a granitic intrusive. The shattered veins are filled with copper — reported assays range between 1.30 and 3.48 percent copper carrying 0.1 ounces per ton in gold and 0.3 to 0.8 ounces in silver (Osterwald and others, 1966).

Some silver, lead and bismuth are reported in the region, although the exact locations of the mineralized deposits are not known. Aughey (1886) reported that the Yankee Jack mine contained a rich, one- to three-foot-thick ore body containing silver sulfide and specimens of metallic bismuth (bismuthinite?). The ore body was reported to extend along a fissure located between a talcose slate hanging wall and a chlorite slate footwall. The Mascotte claim (location also not given) was developed along a one-foot vein — samples of galena were reported to carry 20 ounces per ton in silver. At the Battle Creek lode, argentiferous galena assayed between 12 and 70 ounces per ton in silver. The deposit was developed over a 15-foot-wide zone (Aughey, 1886; Osterwald and others, 1966).

Some tungsten mineralization occurs on the south flank of Copper Mountain (T.40N., R.93W.). The tungsten occurs as scheelite found in a series of gneisses and schists that are cut by several basic dikes, quartz veins, and granitic pegmatite. The scheelite is reported to occur in pods and lenses that parallel the foliation and bedding of the metasediments (Frey and Wilson, 1950). Reported tungsten assays range from a trace to 70 percent WO_3. Only 27 tons of ore have been mined from these deposits (Osterwald and others, 1966).

A number of pegmatites on the southern flank of the range contain lepidolite and feldspar. Some feldspar is mined from the Quein Sabe Mine area to the northeast of Bonneville (Hausel and Holden, 1978), although no production was reported in 1980.

The greenstone terrain of Casper Mountain (Figure 2) is exposed over a limited area. Amphibolite-grade metamorphic rocks invaded by granitic intrusions outcrop over a 8 to 9 square mile region. The metamorphic complex contains amphibolite, serpentinite, quartzite, quartz-feldspar gneiss, and talc and chlorite schists. These rocks are steeply dipping (Burford and others, 1979).

Mineralization in this greenstone region is poorly expressed. Some feldspar and beryl are sporadically mined from pegmatites. In the 1890's, Casper Mountain was noted for containing important resources of cross-fiber asbestos and chromite, although only limited tonnages of each commodity were mined. Only minor amounts of gold and silver have been reported (Beckwith, 1939; Burford and others, 1979; Hausel and Glass, 1980; Kinttel, 1979; Molker, 1923).

The Granite Mountains (Figure 2) have not been studied in detail. Amphibolites, ultramafic rocks, quartzite, iron formation, and layered schists are present. Mineralization includes banded iron formation, some copper, lead, zinc, and minor gold (Harrer, 1966; Hausel and Glass, 1980; Love, 1970; Osterwald and others, 1966; Pekarek, 1977). Very little ore has been mined from this greenstone terrain.

The Seminoe Mountains greenstone belt (Figure 2) (also known as the Seminoe District) contains deposits of gold, copper, and iron. Small deposits of asbestos, talc, and nephrite (Wyoming jade) are reported, but these appear to have little commercial value. The Seminoe Mountains greenstone belt is formed of mafic and ultramafic metavolcanic rocks; a sedimentary succession containing iron formation, metagraywacke, quartzite, and pelitic schist; and metagabbro, granodiorite, and aplite intrusive phases (Bayley, 1968; Klein, 1981). Gold-copper deposits in the district occur in quartz veins hosted by metagabbro country rock and as localized disseminations in ultramafic rocks. Some gold mineralization may be present in the iron formations.

These deposits occur as gold and copper in quartz veins in the Penn Mine area of Bradley Peak (sec. 6, T.25N., R.85W.). The veins range from small, sub-parallel quartz stringers to veins up to three feet thick. These trend from due north to N20°E.

Gold occurs in sulfides — the primary sulfides are pyrite, chalcopyrite, and minor sphalerite. Native gold associated with limonite, copper carbonate stains, and limonitic boxworks occurs in the weathered veins near the surface. Reported tenor of the veins by Aughey (1886) was 0.5 ounces of gold per ton. This tenor may be reasonable in that a selected grab sample of dump material assayed 2.9 ounces in gold per ton and some hand specimen samples collected from the dump contained visible gold (Hausel, 1981b).

Alteration of the host ultramafic flows and metagabbros includes silicification, carbonatization, and chloritization. Silicification is expressed in a distinct bleaching of the wall rocks, and extends several feet from the veins into the wall rocks. Carbonatization is more widespread in the mineralized areas, and often is recognized as massive carbonate replacements accompanied by fine-grained chlorite in the metavolcanics (Klein, 1981).

Sulfide quartz veins in the Junk Creek prospect area (S½ sec. 20, T.26N., R.85W.) and copper-quartz veins at the Sunday Morning prospect (SE¼ sec. 29, T.26N., R.85W.) occur in east-west to northeast trending cataclastics developed in metavolcanic successions. Mineralization at Junk Creek occurs as copper carbonates and sulfides in quartz veins and in an aplite dike. At the Sunday Morning prospect, copper silicates and oxides occur as impregnations in fractured quartz vein material near several altered, structurally controlled porphyritic intrusions (Klein, 1981). The highly silicified intrusions have granodioritic compositions. The primary copper ores have been replaced by cuprite, chrysocolla and minor malachite (Hausel, 1981c).

At the Kopper Pit prospect (NW¼sec. 33, T.26N., R.85W.), chalcopyrite is disseminated in altered ultramafics. Mineralization at the Sunday Morning Mine (sec. 21, T.26N., R.85W.) occurs as gold associated with felsic metavolcanic and metasedimentary sequences. (G. Marlatt, pers. comm. 1982).

Generally, the gold-bearing copper sulfides in the Seminoe District are associated with light- to dark-gray quartz veins. The veins are generally concordant with the regional foliation (Klein, 1981).

Iron formations in the district occur as banded quartz-magnetite-amphibolite units. At many localities, oxidation is extensive and hematite is formed at the expense of magnetite (Bayley, 1968). The structure of the formations is quite complex with numerous faults and cross-cutting metagabbros. In places, the iron formation is 300 feet thick. Potential iron formation resources are estimated by the U.S. Bureau of Mines at 50 to 100 million tons of iron ore (Harrer, 1966).

Of additional interest is the possibility of gold in the iron formation. At two separate localities, reconnaisance chip samples were selected from the formation, where the iron formation exhibited alteration similar to that found near the Penn Mines. These initial samples assayed better than one ounce per ton in gold. (It should be pointed out that the initial samples have not been verified by follow-up samples.) If these iron formations do indeed contain some gold as predicted by the initial assays, it would not be unusual in that iron formations elsewhere commonly contain above-normal gold concentrations (Boyle, 1976; Fripp, 1976b; Watson, 1976; Windley, 1979). The association of the gold with replacement textures and the apparent spotty values (Lovering, 1929, p. 230) may indicate that the gold is epigenetic.

The early development of the Seminoe District was for gold in the quartz veins. The Penn Mining Company developed several mines (Deserted Treasure, Emeletta, Star, Hope, King, Jennie, Meager and Bennett) that are presently known as the Penn mines. A ten-stamp gold-quartz mill and concentrator were constructed on the property to process the ore. Development work on the mines was not extensive, and the mine workings may only total about 500 feet in length on the quartz veins (Klein 1981). None of the Penn mines are accessible at the present time.

Several other blocks and masses of greenstone-belt-type rocks have been recognized in Wyoming. These include Heath's Peak in the northern Laramie Range. The Heath's Peak area may be a fragment of the Seminoe Mountain greenstone engulfed by younger granite. The area is mineralized along its border as well as within quartz-muscovite-graphite schist. Deposits include pyrite, pyrrhotite, molybdenite, marcasite, chalcopyrite, sphalerite, galena, and uraninite. Greenstone-belt-type terrain is also reported in the Esterbrook region of the northern Laramie Range and in the Elmer's Rock area of the central Laramie Range (Karlstrom and others, 1981). Both of these areas are poorly mineralized, although the Esterbrook area had some historical copper and lead production (Spencer, 1916).

In the Esterbrook District of the northern Laramie Range, Archean metasediments intruded by igneous bodies contain several fissure-filling and, possibly, 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, 1962; Osterwald and others, 1966; Spencer, 1916).

The Esterbrook mines were small, even though Spencer (1916) reported fairly extensive deposits. As an example, the Esterbrook Mine (sec. 10, T.28N., R.71W.), located in the middle of the village of Esterbrook, was reported to contain massive galena shoots up to six feet wide (although mine dump samples show only minor galena mineralization). The deposit has limited alteration and is classified as shallow-depth epithermal (Greeley, 1962).

The Garret area, located on the southwestern edge of the Laramie batholith has characteristic greenstone belt rocks, as do areas in the northern Medicine Bow and Sierra Madre mountains (Karlstrom and others, 1981).

The South Pass greenstone belt (Figure 2) is the most extensively studied greenstone in Wyoming because it contains 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 amygdaloidal metabasalt, metatuff, meta-andesite, hornblende schist, and amphibolite, which are mapped as the Roundtop Mountain Greenstone. The sedimentary group includes both the Goldman Meadows and Miners Delight formations. These rocks include metagraywacke, pelitic schists, conglomerate, quartzite, and iron formation. Intrusive phases are serpentinite, metagabbro, metadacite and 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 metagraywacke. These shears formed conformable with the grain of the wall rock. Silicification followed shearing and resulted in 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 predominately amphibolite grade with a small block of greenschist facies (Bayley and others, 1973).

Iron formations in the South Pass greenstone are mined by U.S. Steel Corporation at their Atlantic City open pit mine (T.30N., R.100W.). 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 1962.

In the South Pass area, disseminated gold occurs in arsenopyrite-quartz veins that generally follow the grain of wall rock and occupy shear zones. These veins are often sheared themselves. The majority of the historic gold mines lie along northeast trending, sheared metagabbros which intrude the main body of the Miners Delight Formation (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,

Figure 4. The more productive historic gold mines in the South Pass area were developed along quartz veins (A) in sheared metagabbro (the quartz vein lies between the two drafted arrows immediately above the collapse breccia in the adit). Such mines as the Miners Delight (B) and Carissa (C) were important gold producers in the early to late 1870's. Photographs by W.D.H., 1978.

1947). Some weak mineralization and limited production came from shear zones in metagraywackes of the Miners Delight Formation.

The mineralized veins occur as massive quartz with some 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, within a broader zone of sericitization (Bayley and others, 1973).

The South Pass area was an active gold mining camp during the gold rush of the late 1860's (Chisholm, 1960). It is estimated that as much as 325,000 ounces of gold may have been produced from auriferous arsenopyrite-quartz veins and associated placers (Hausel, 1980a) (Figure 5).

Essentially all of the gold mines and prospects of the South Pass greenstone ceased production once the oxidized ores gave way to the unoxidized, unweathered sulfide deposits. Apparently production terminated because of excessive extraction costs and the inefficient extractive technology used during the late 1800's and early 1900's. For example, mine tailings below at least one stamp mill contain excessive quantities of native gold, indicating that a fair amount of the precious metal was lost during milling (E.C. Winters, personal communication, 1981).

Initially, the oxidized ore was mined and generally presented no complications, as much of the gold was free milling and inexpensive to extract. These deposits were developed to a maximum depth of 400 feet at the Carissa Mine. The oxidized ore gave way to unoxidized sulfide and arsenide ore. These ores, being refractory and lower in grade, were expensive to produce and the precious metal difficult to extract. When the oxidized ore was depleted, it signaled the end of the mining venture.

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. Recent interest in the South Pass area by a number of mining companies points to the potential importance of the greenstones. Presently, four small placer operations are actively mining gold in the South Pass greenstone.

To date, major stratiform gold mineralization in banded iron formations, and strata-bound sulfide deposits in differentiated mafic to felsic volcanics, have not been reported in the Wyoming greenstones. Because such deposits are mined in similar terrains in Africa and in the Canadian shield (Fripp, 1976a,b; Roberts, 1975; Spence, 1975; Windley, 1979), their potential existence in this state invites future exploration.

URANIUM IN METACONGLOMERATE

Metaconglomerates in the Proterozoic miogeosynclinal successions of the northern Sierra Madre and Medicine Bow Mountains are host to placer uranium mineralization. The conglomerates (Figure 6) apparently were deposited in continental marginal basins by southward-flowing, braided stream channels and other river systems. Favorable placer traps hosting detrital heavy minerals such as pyrite, gold, uranium, and thorium are primary exploration targets in these types of deposits.

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 areas 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, 1978, 1979; Karlstrom, 1977; Karlstrom and Houston, 1979a, 1979b; Karlstrom and others, 1981; Lanthier, 1979; Miller and others, 1979). As much as 0.14 percent U_3O_8 (anonymous, 1981) and localized subeconomic gold (Paul Graff, personal communication, 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 on the metaconglomerates (Houston and Karlstrom, 1979).

IRON ORE AND COPPER IN EUGEOCLINAL SUCCESSIONS

Significant iron formation reserves and some copper deposits occur in Precambrian (Archean?) eugeosynclinal metamorphic rocks in the Hartville Uplift of southeastern Wyoming (Figure 2).

The iron ore, formed of massive and specular hematite, occurs in, and grades into, the lower part of the Good Fortune Schist, a hematite schist (Archean?) (Harrer, 1966; Millgate, 1965; Osterwald and others, 1966). Minor amounts of siderite and limonite are associated with the hematite. No marcasite or pyrite have been observed in these rocks. The hematite ore contains some calcite, quartz, gypsum, chalcedony, barite, clay, chrysocolla, malachite, chalcocite, azurite, and native copper gangue. The copper occurs in fractures within the hematite and clearly was formed later than the hematite (Ball, 1907).

In places, the iron formation is several hundred feet thick (Ball, 1907). It occurs within folded and faulted, steeply dipping metasediments and metavolcanics that crop out on the eastern flank of the Hartville uplift. The formation extends through the Sunrise and Good Fortune mines toward the center of the uplift (sec. 7, T.27N., R.65W.), and to the west extends under gently dipping Paleozoic sediments (Harrer, 1966; Millgate, 1965).

The massive hematite and specularite occurs in pods that are thickest where overlying carbonates are thinnest and where much of the schist is silicified. This relationship suggests that some of the hematite is secondary and was formed by groundwater oxidation and enrichment of the original ferruginous beds during carbonate dissolution (Ebbett, 1956; Snyder, 1980).

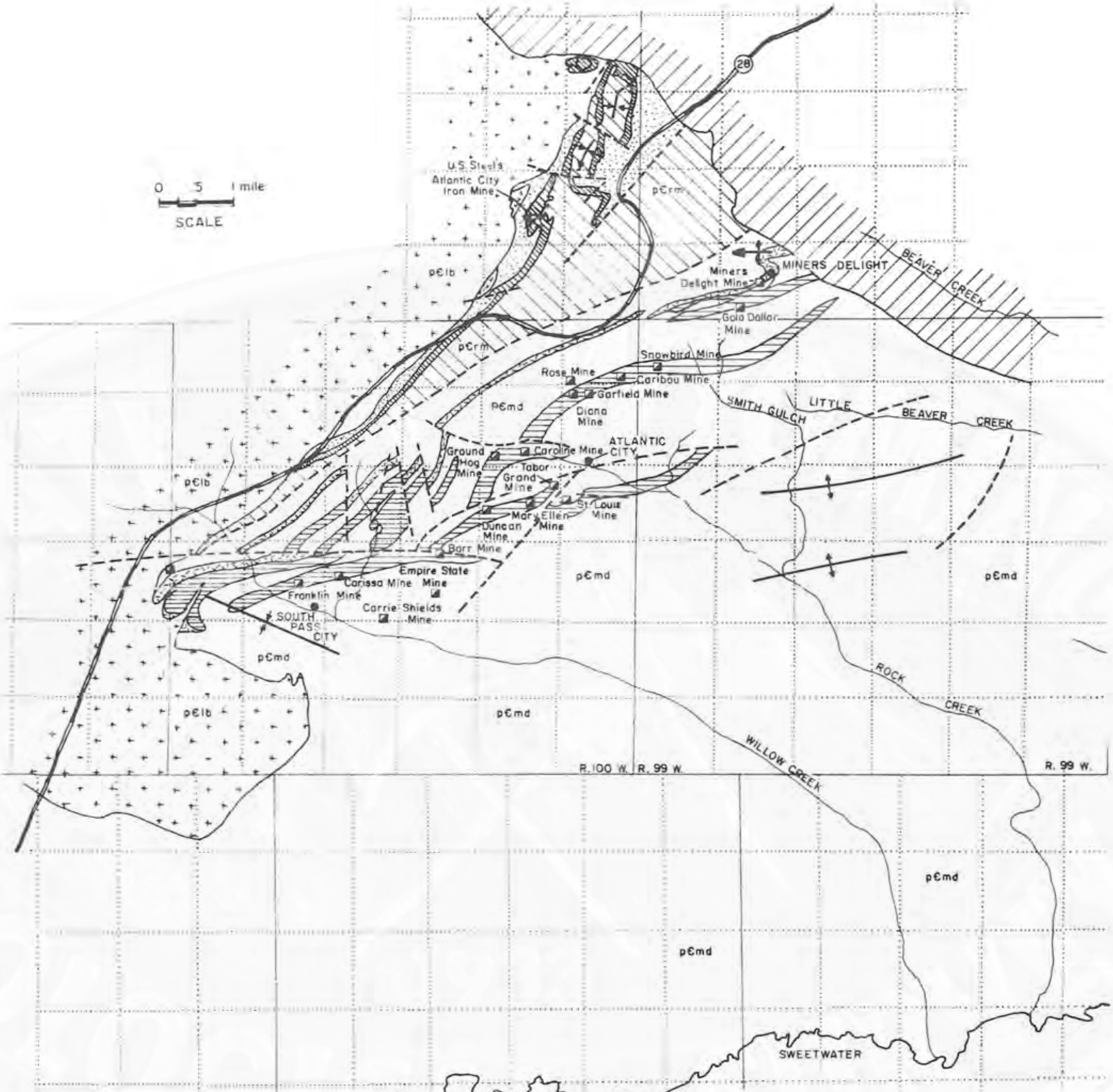
Additional iron deposits (presently uneconomic) in the Hartville Uplift occur as Precambrian hematitic gossans that grade downward into pyrrhotite-pyrite fault breccia (Precambrian?) along the McCann Pass fault, as local concentrations of hematite-copper associated with Paleozoic karst surfaces, and as hematite-uranium concentrations associated with Laramide faults in the vicinity of the Silver Cliff Mine (sec. 7, T.32N., R.63W.) (Bromley, 1953).

The Sunrise is the only active iron mine in the district (Figure 7). Iron ore has been mined in the district since 1889 (Harrer, 1966; Millgate, 1965; Osterwald and others, 1966).

The extracted ore is shipped to Colorado Fuel and Iron Company's blast furnaces in Pueblo, Colorado, where it has been 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 resume production.

The iron ore, described as hematite schist, is formed of 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 and nearby 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.

At the Copper Belt mines (secs. 2,3,10,11, T.30N., R.64W.), shattered quartz veins contain stringers of chalcocite, bornite, malachite, chrysocolla, and azurite. Common copper assays range from 2 to 8 percent with some assays reported as high as 30 percent copper; gold values were reported to average about 0.16 ounces per ton with 2 to 5 ounces of silver. Some veins were emplaced in schist, others at the contact between hanging-wall dolomite and foot-wall mica schist. 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, ZINC, AND LEAD IN ISLAND ARC VOLCANOGENIC SCHISTS

From 1899 to 1908, approximately 24,000,000

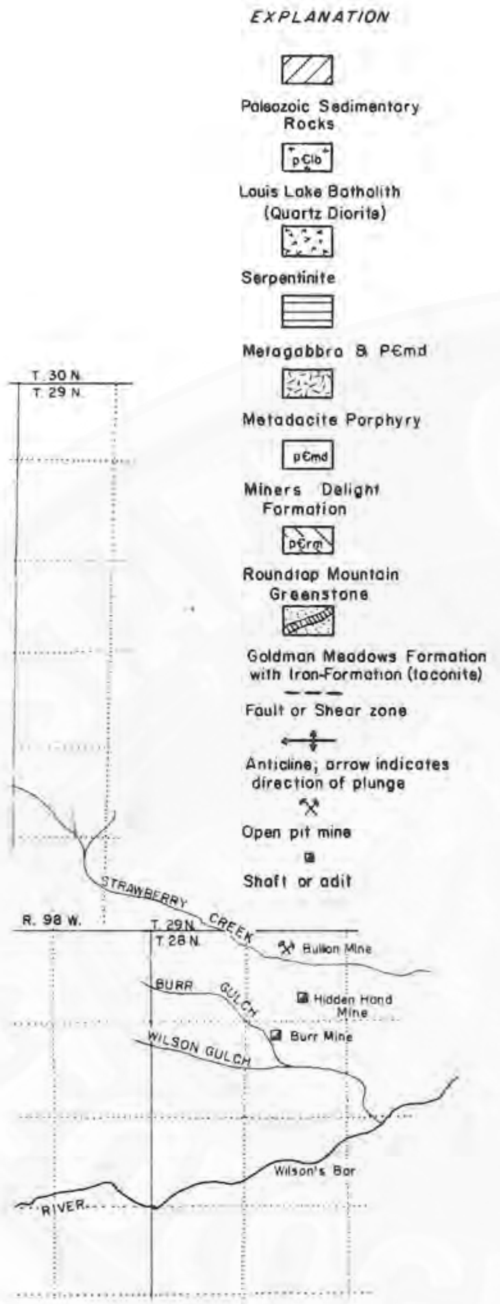


Figure 5. [Above and opposite] *During the 1870's the South Pass region experienced a gold rush. Four mining camps were organized within the South Pass greenstone belt — South Pass, Atlantic City, Miners Delight, and Lewiston (Armstrong, 1947; Bayley and others, 1973; Hausel, 1980a). Gold veins, mineralized fissures, and placers were the primary targets of prospectors; the more productive gold veins were associated with metagabbro intrusive phases and were conformable to the grain of the host metagabbros (Bayley and others, 1973). Modified from Bayley and others (1973).*

pounds of copper were produced in Wyoming; much of it was mined from the Encampment District in the southern Sierra Madres (Osterwald, and others, 1966). Since 1908, very little exploration and development have occurred in this region, although the potential for economic mineralization still exists.

The Green Mountain Formation, south of the Mullen Creek–Nash Fork shear zone in the southern Sierra Madre Mountains, has a number of characteristics that suggest a potential for 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 apparent island-arc environment. A number of relic textures, such as vesicular, agglomeratic, and porphyritic textures, are retained by these metavolcanics (Divis, 1976, 1977).

Lindgren (1908), Osterwald and others (1966) and Spencer (1904) have reported 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 are described as (1) disseminated mineralization in hornblende schist, (2) tactite-like garnet epidote streaks, (3) bedding replacement bodies in quartzitic layers in the schist, (4) hornblendic contact metamorphic zones bordering diorite-gabbro intrusives, and (5) quartz veins and pegmatities.

Mineralization of several of these deposits in the southern Sierra Madre described by Spencer (1904), Lindgren (1908), and Osterwald and others (1966) may be of the volcanogenic syngenetic type, and some of these should be reexamined in light of possible volcanogenic genesis. For example, at least one deposit in the Huston-Fletcher Park area displays massive pyritized ore with colloform texture adjacent to volcaniclastics ("mill rock"?) (Figure 8). Mineralization of this deposit, known as the Itmay Mine (sec. 14, T.13N., R.86W.), is reported by Osterwald and others (1966) to be chalcopyrite-pyrite ore assaying as rich as 17.92 percent copper with 0.05 ounces of gold per ton, localized along the walls of, and impregnated within, an altered basic dike (alteration pipe?) intruded into quartz diorite. At other localities in this general region, tenorite-malachite-stained rock with associated spotty marmatite can be traced several yards along outcrop and appears to be syngenetic.

Although none of these deposits have been proven to be volcanogenic massive sulfides, the environment in which they were formed and the mode of mineralization are suggestive that the Green Mountain Formation could host important syngenetic base and precious metal resources.

Several other deposits in the southern Sierra Madres described in old mine reports are of potential economic interest. The Hinton Mine (sec. 32, T.13N., R.85W.) located within the Green Mountain Formation contains chalcopyrite-magnetite mineralization hosted by hornblende schist. A reported assay produced 8.18 percent copper and 0.02 ounces per ton in gold. The Broadway Mine lies outside of the Green Mountain Formation. This deposit is described as an irregular zone of sphalerite trending along the contact between granite and a series of gneisses and amphiboles. The sphalerite body occurs in a 1000-by-10-feet-wide zone averaging 3 to 35 percent sphalerite. The sphalerite is suggested to have replaced amphibolite. Associated minerals include galena, chalcopyrite, chalcocite, covellite, malachite, and chrysocolla. One reported assay of a channel sample gave 12.5 percent zinc, 1.9 percent lead, and 0.02 percent copper (Osterwald and Albanese, 1947; Osterwald and others, 1966).

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 metavolcanics (Figure 9) (Hausel, 1981e,; Hausel and Roberts, 1981; Klein, 1974). Drilling has substantiated several small ore bodies. At the Copper King Mine in the southern portion of the district, 10 million tons of 0.30 percent copper and 0.038 ounces of gold per ton are indicated to a depth of 500 feet. Drilling has also shown that the ore body continues to at least 700 feet deep before rapidly decreasing in size. The ore is epigenetic and is possibly derived from the leaching of metasedimentary and metavolcanic rocks during the emplacement of the Sherman Granite batholith (Klein, 1974).

SHEAR-ZONE MINERALIZATION

The Mullen Creek–Nash Fork shear zone (Figure 2) represents a boundary between the Archean

A

B

C

Figure 6. A and B, core splits of quartz-pebble conglomerates, Medicine Bow Mountains. (A) Grain size fining upward (top to right), typical of the metaconglomerate sequences. (B) Minor pyrite mineralization (between arrows) in weakly radioactive zone near large quartz pebbles. (C) Stretched-pebble paraconglomerate in the central Laramie Range. These types of deposits represent placer deposition in a fluvial environment. Reducing (oxygen-deficient) atmospheric conditions provided by the primitive Precambrian atmosphere were necessary to the transportation and deposition of uraninite and pyrite in the placer environment. Photographs by A.J. Ver Ploeg, 1982, W.D.H., 1980.

Figure 7. Colorado Fuel and Iron Company's Sunrise Mine in the Hartville Uplift. The mine has a rated annual capacity of approximately 600,000 tons. Hematite is mined from iron formations, and the ore is shipped to C.F. & I.'s blast furnaces in Pueblo, Colorado (Hausel, 1978). Photograph by W.D.H., 1980.

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. 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 much potential economic value.

Several mines were developed in sheared cataclastics during the early mining history of Wyoming (Curry, 1965; Hausel, 1980a, 1980b; McCallum, 1968; McCallum and Orback, 1968), principally for gold, copper, and platinum group mineralization (Figure 10). 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 ore was produced that commonly assayed 25 to 30 percent copper with traces of platinum group metals (McCallum and Orback, 1968).

In the Centennial Ridge District, two types of primary ore deposits are recognized. Primary gold deposits occur in quartz veins which parallel the foliation and schistosity of amphibole- and mica-bearing gneisses and schists of the Mafic Series unit. These primary gold deposits were the most economically important in the district and were developed at the Free Gold, Utopia, and Centennial mines. Primary gold-platinum deposits occur in shear zones, faults, and quartz veins where they cut mafic series rock units (Figure 11). The precious metals are associated with sulfides and arsenides which occur as fracture and breccia fillings (McCallum, 1968); these deposits are spotty, and were not developed to any great extent (Hausel, 1980b; McCallum, 1968).

The ore solutions in these shear zones were probably hydrothermal. Because of the close association of mineralization with the Mafic Series unit, 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-ILMENITE

During the Late Proterozoic (1.5 b.y. ago), the Mullen Creek-Nash Fork shear zone at the present site of the central Laramie Range was intruded by anorthosite of batholithic proportions (Figure 2). The surface extent of the Laramie anorthosite is about 350 square miles. The anorthosite has 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 examined for its aluminum potential (Hagner, 1951; Harrer, 1954), but presently the expensive process of separating aluminum from feldspar cannot economically compete with the processing of aluminum-enriched bauxites. However, the anorthosite does represent a potential resource for industrial minerals (Shutt, 1970; Hausel, 1981f). Large bodies of anorthosite, containing essentially no accessory minerals, could be economically mined for their

A

B

Figure 8. [Above] *(A) Massive pyritized ore with colloform texture. This sample, collected in the Sierra Madre, exhibits rounded grains of pyrite mantled by chalcopyrite. The matrix is magnetite with minor chlorite. (B) "Mill rock." Felsic volcaniclastics are often found in close proximity to massive ore, as at this locality in the Sierra Madre. Felsic volcanic breccias are mapped in Canada as tracers to ore. Sangster (1973) dubbed it "mill rock" because whenever he was standing on a volcaniclastic with large fragments, he could "hear the sound of a mill." Presumably, the volcaniclastics occur near minable ore and represent a fossil volcanic orifice from which the metallic sulfides originated. Photographs by W.D.H., 1978.*

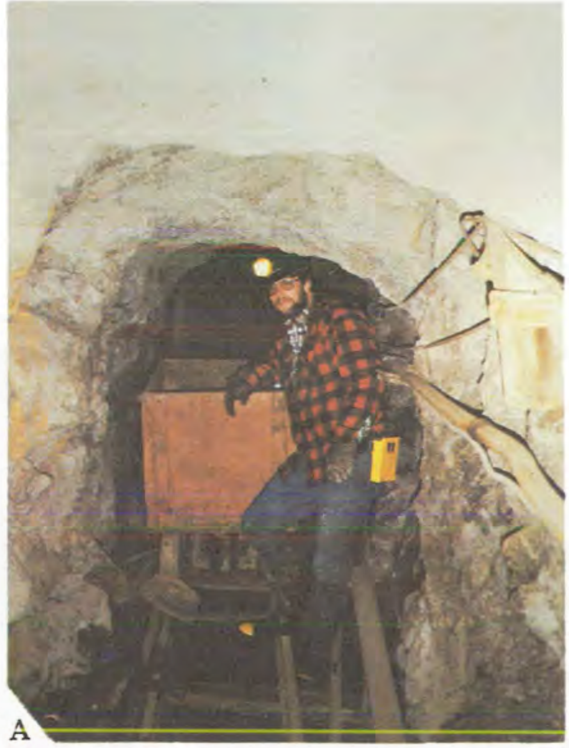


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Figure 9. [Right] *The Comstock copper mine in the Silver Crown District was developed by a 200-foot-deep shaft which was intersected by a tunnel with 500 feet of mine workings. The shaft was developed along an ore shoot formed by N20°E and N40°E mineralized veins in foliated granodiorite. The adit and tunnel were developed to intersect the shaft, and cut through several small, blind mineralized fissures and quartz veins. (A) Much of the old equipment remains in the mine. The major lodes were either mineralized fissures or mineralized quartz veins. (B) This portion of a vein adjacent to the Comstock lode shows the mineralized quartz vein adjacent to sheared gneissic granodiorite* [left] *and massive monzonite* [right]. *Photographs by W.D.H., 1981.*

Figure 10. (A) The Platinum City Mine dump and (B) Queen Mine headframe in the Centennial Ridge District. Photographs by W.D.H., 1980.

sodium-rich feldspar to be used as a fluxing agent in glass production. Nearby resources of calcium carbonate and glass sands in the Casper Formation are also available for use as a stabilizing agent and as a component of 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 mineral aggregate (Hagner, 1968; Osterwald and others, 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 Gold Hill District of the northern Medicine Bow Mountains, 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 Mullen Creek-Nash Fork 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 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, see Hausel (1980a) and Osterwald and others (1966).

MISCELLANEOUS PRECAMBRIAN MINERALIZATION

Some Wyoming jade (nephrite) and marble are collected and mined from Precambrian terrain each year. The jade is used as a lapidary stone, and the marble is used mainly as a decorative stone for landscaping. Approximately 52 thousand tons of Laramie Range marble were produced in 1980 by Basins Engineering (T.24N., R.70W.). No production records are kept for jade.

Late Precambrian and Early Paleozoic rocks contain very few recognizable mineral deposits. Some simple pegmatites, formed as last crystallizing phases of the Sherman Granite batholith, were mined in the 1940's and 1950's for their feldspar content. These pegmatites are small, have limited tonnages, and are diluted with quartz.

The most important deposits of the early Paleozoic in Wyoming appear to be diamond-bearing kimberlite.

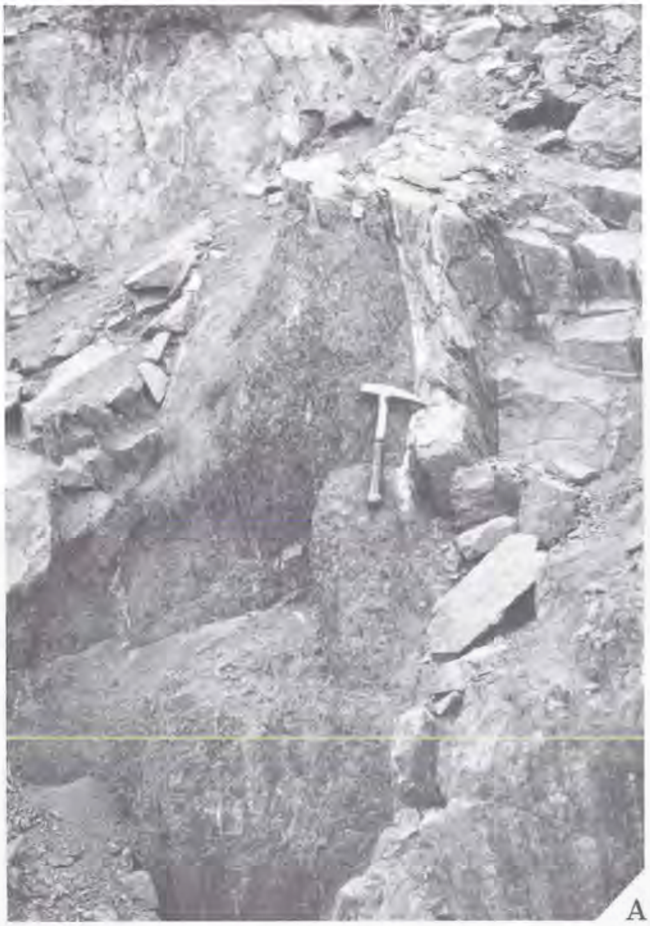

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Figure 11. (A) Shear zone cataclastics near the Platinum City adit and (B) shear zone developed on the east side of Middle Fork Canyon. These shear zones were important localizers of platinum-gold deposits, especially where they were developed in Mafic Series rocks. The source of the metals is believed to have been the Mafic Series units. Photographs by W.D.H., 1980.

GEOLOGIC SETTINGS FOR PALEOZOIC MINERALIZATION

Recognized important Paleozoic mineral deposits in Wyoming are limited to Devonian kimberlite intrusives which crop out in the Laramie-Front Range and 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 of shallow seas is recorded in the Paleozoic sedimentary record. The progressive thickening of marine sediments to the west reflects geosynclinal sedimentation in Idaho. No important mineral deposits are recognized in these early Paleozoic sediments. However, by the Devonian, a tectonic disturbance had produced deep fractures that penetrated the earth's crust and tapped magma from the upper mantle. At least 90 ultrabasic intrusives were emplaced along these fractures from as far north as Sybille Canyon in the central Laramie Range of Wyoming to as far south as Boulder, Colorado. These ultrabasic intrusives, or kimberlites, contain xenoliths of predominantly Ordovician and Silurian carbonate sediments and some Cambrian(?) sandstones. Some kimberlites are mineralized with 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. Both dolomites and limestones were deposited.

In southeastern Wyoming, Pennsylvanian 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 during 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 extended 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 late Paleozoic(?) 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 KIMBERLITE

More than 90 kimberlite intrusives are scattered over a 120-mile, north-south trending region in the Laramie-Front ranges (Figure 12). These ultrabasic 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 in this province are diamond bearing (McCallum

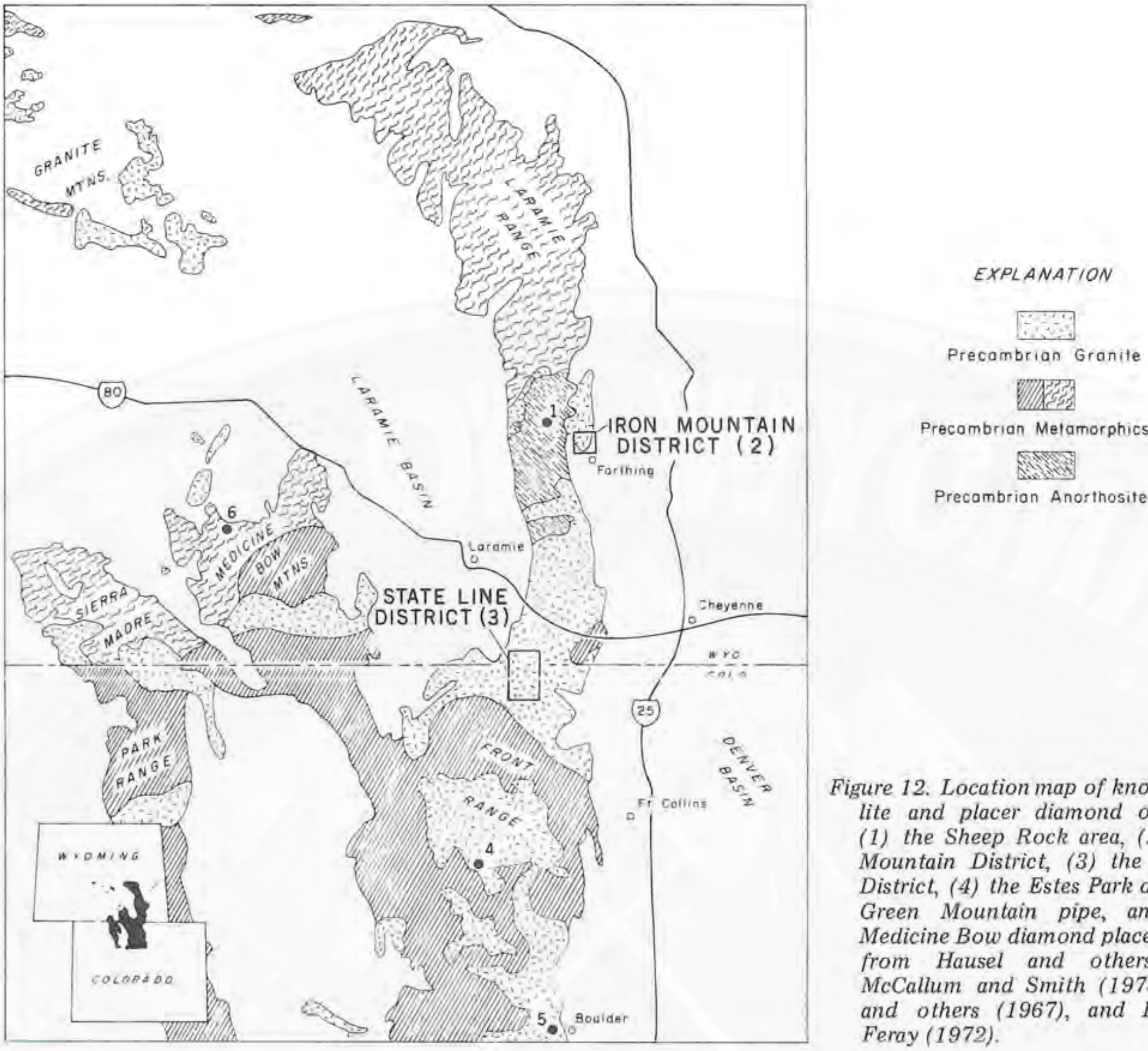

Figure 12. Location map of known kimberlite and placer diamond occurrences: (1) the Sheep Rock area, (2) the Iron Mountain District, (3) the State Line District, (4) the Estes Park dike, (5) the Green Mountain pipe, and (6) the Medicine Bow diamond placer. Modified from Hausel and others (1979b), McCallum and Smith (1978), Oetking and others (1967), and Renfro and Feray (1972).

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 13).

The Iron Mountain District, 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. They are mapped as continuous systems on the basis of the presence of bluish-gray montmorillonitic clays, residual mafic 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, but one dike-blow system extends nearly one mile (McCallum and others, 1975; McCallum and Smith, 1978; Smith, 1977). No diamonds have been found within this district (M.E. McCallum, personal communication, 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 are concerned with 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.),

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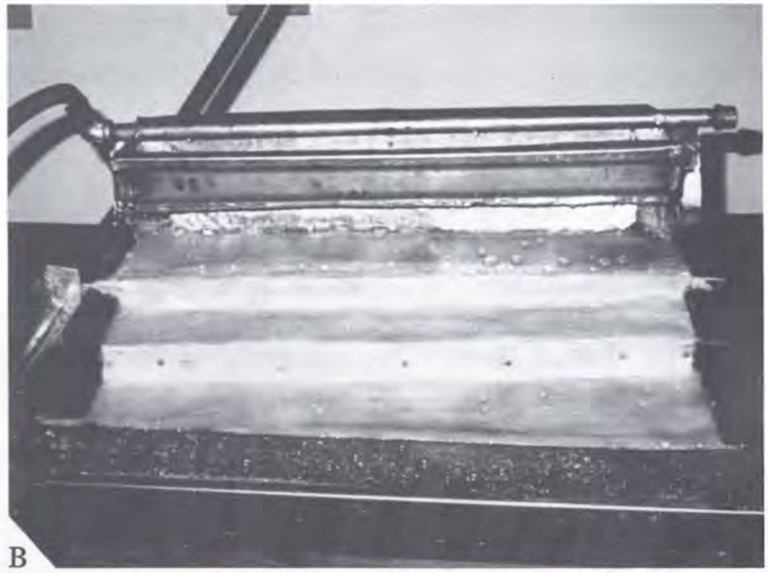

B

Figure 13. (A) Radichal 1 kimberlite, a small kimberlite intrusive that crops out in the anorthosite batholith in the Sheep Rock area. (B) Diamond testing using grease tabling at the Geological Survey of Wyoming. Because diamonds are not wettable, they are attracted to the grease. Photographs by (A) W.D.H., 1980, and (B) A.J. Ver Ploeg, 1980.

Figure 14. [Right] *Exposed kimberlite-granite contact. The contact is sharp and shows essentially no hydrothermal alteration effects. Photograph by W.D.H., 1981.*

geology and geochemistry (Chronic and others, 1969; Eggler, 1967, 1968; Hausel and others, 1981; Hausel and McCallum, 1980; McCallum, 1979; McCallum and Mabarak, 1976a,b), and mineralogy and petrology (Eggler and McCallum, 1973, 1974, 1976; McCallum, 1976; McCallum and Eggler, 1968, 1971, 1976; McCallum and Mabarak, 1976a, 1976b; McCallum and others, 1975, 1977, 1979; 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). These kimberlites apparently were intruded as a relatively cool mass — the host granites show essentially no alteration affects (Figure 14).

Several hundred to possibly a few thousand vertical feet of diamond-bearing kimberlite have been removed by erosion in this district (McCallum and Marbarak, 1976b, Figure 6, p. 7). The possibility of diamond-bearing alluvial placers downstream from the kimberlites has not been examined for potential economic mineralization although such studies will undoubtedly be considered if economic mineralization is proven for any of the kimberlites.

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 testsampling kimberlite in the Wyoming State Line District, which they refer to as the Fish Creek Project. Cominco is presently operating a diamond extraction research facility in Fort Collins (Miller, 1980). Superior Minerals is conducting a similar bulk sampling and testing program in Colorado.

The Estes Park dike, located 45 miles south into Colorado, and the Green Mountain pipe, 70 miles south of the state line, are small intrusives. 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. Of interest also are placer diamonds found within the Medicine Bow Mountains (Hausel, 1977; Hausel and others, 1979a, 1979b), unverified reports of diamonds in the Sierra Madres (P.J. Graff, personal communication, 1980), and in the Gros Ventre and northern Wind River ranges (J.D. Love, personal communication, 1981); the occurrence of pyrope garnet and chrome diopside in ant hills of the Green River Basin (T. McCandless, personal communication, 1979; Hausel and others, 1979b), and the reported occurrence of similar indicator minerals south of Heart Mountain in the Bighorn Basin (J.C. Antweiler, personal communication, 1980). Undoubtedly, more kimberlites will be discovered in the Colorado-Wyoming region in the 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 on the western flank of the Laramie Range (Figure 15). The limestone averages 90 percent $CaCO_3$ and is used in the manufacture of cement. Production in 1980 totalled 382,000 tons. The quarry has been 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 percent $CaCO_3$, and is used by the sugar beet industry. Presently, Great Western quarries rock south of Interstate 80 about 4 miles from Granite. However, up to 1978, the limestone was mined underground from steeply dipping beds at the Horse Creek Mine. The limestone at Horse Creek is mined out, but 5 years of reserves are stored on the property (Figure 16). 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 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 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 (tyuyamunite and metatyuyamunite) in the Little Mountain area (Figure 20) of north-central Wyoming occurs as epigenetic deposits coating fractures and filling vugs in limestone breccias and is 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 by Hart (1958) to have occurred during late Eocene time, but this has not been verified by age dating.

The largest known deposit in the Little Mountain area is the east ore body of the Fusner (Lisbon) mines. The deposit occurs in an irregular cavern which terminated on its western edge at a joint plane. The length of the cavern followed the strike of the joint, and the cavern measured 150 by 35 to 80 feet with a height of 20 to 25 feet. Uranium was found in a fanlike deposit formed by reddish-brown silts derived from the Amsden Formation. The fan also contained angular limestone fragments. About 5,000 tons of ore were produced from the mine averaging 0.80 percent U_3O_8 (Osterwald and others, 1966).

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

COPPER-SILVER-ZINC

See below under Mesozoic Mineral Deposits.

PHOSPHATE

The Phosphoria Formation in western Wyoming contains thick accumulations of phosphorite. The phosphorite occurs as microcrystalline carbonate-fluorapatite or francolite. Common trace elements associated with the phosphorite are fluorine,

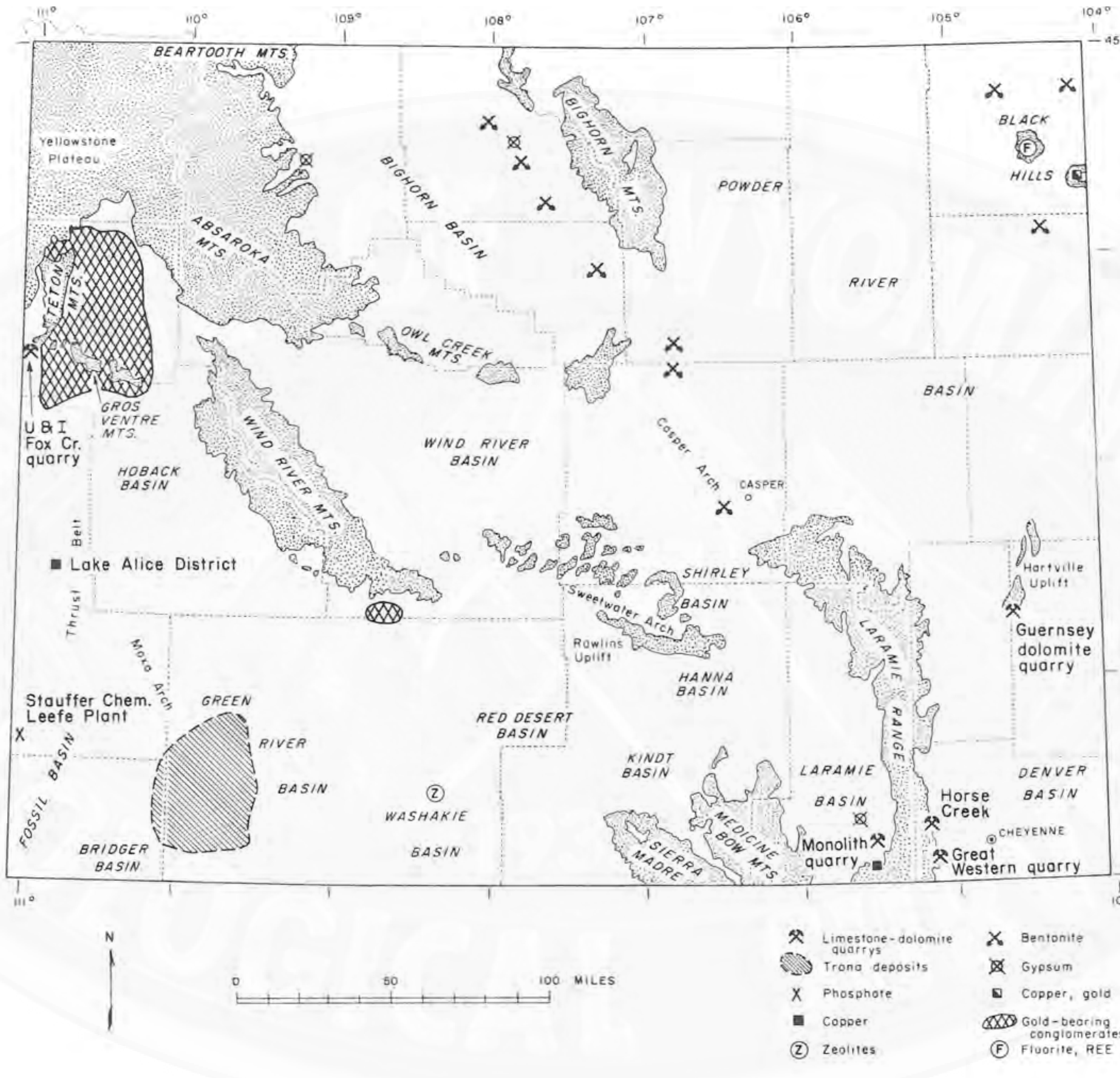

Figure 15. Location map of miscellaneous mineral occurrences.

Figure 16. Great Western's Horse Creek property. Quarrying of this property began in 1912, and underground methods were initiated in 1926. The limestone occurs in two steeply dipping (80°NE), massive beds that average 23 feet thick. The footwall is dolomite, the hanging wall a 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.D.H., 1980.

uranium, selenium, and chromium (McKelvey, 1946; Sheldon, 1963).

The phosphorites form major accumulations of phosphate in the Overthrust Belt region, an area characterized by tight folding and thrust faulting. Intense thrust faulting has destroyed the economic value of many outcrops of the Phosphoria Formation in this region. 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 are much thinner (Bates, 1969; King, 1947). East of the Wind River Range, the phosphate units gradually undergo a facies change to carbonate rocks of the Park City Formation.

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

The total phosphate resource in Wyoming's Phosphoria Formation is estimated at about 2.5 trillion tons, averaging 9.0 percent P_2O_5 and 0.0033 percent (33 ppm) uranium (Bauer and Dunning, 1979). More than 2 trillion tons of this resource are not considered minable under 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 in Wyoming near the Idaho border (Figure 15). Presently, phosphate is not mined in Wyoming.

GEOLOGIC 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 sediments was affected by the development of the deep, north-trending geosyncline 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 developed in eastern Wyoming in the Triassic, notably the 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. Copper mineralization, along with some silver and zinc are also found in red bed deposits in the Overthrust Belt of western Wyoming.

The Cretaceous included many episodes of marine transgression and regression. Extensive peat swamps are associated with these transgressive/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 ash falls in shallow seas and lakes during the late Cretaceous. Alteration 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. Copper, silver, and zinc mineralization is reported in red bed sandstones in the Overthrust Belt of western Wyoming.

During the Cretaceous, large portions of the state were covered by shallow seas. Nearshore environments were swampy with extensive lagoons that were sites of 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 ash falls were 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. The more economically important gypsum beds occur in the Satanka-Forelle, Chugwater, and Gypsum Spring formations (Hausel and others, 1979).

During 1980, Wyoming gypsum mines produced 296,100 tons of ore. Gypsum was produced in Albany, Big Horn, and Park counties (Figure 15). In Big Horn and Park counties, gypsum was mined from Jurassic strata and used in sheet rock manufacturing, and in Albany County, gypsum is mined from Satanka-Forelle rocks and used as a cement additive at the Monolith Plant in Laramie. Gypsum, in Wyoming, has been mined sporadically since 1890 (Osterwald and others, 1966).

COPPER - SILVER - ZINC

Copper deposits in Lincoln County are reported in sedimentary (Pennsylvanian to Cretaceous) strata (Figure 15). Copper is reported in the Wells(?) Formation, in the Nugget Sandstone (Triassic(?)-Jurassic(?)) and in the Beckwith(?) Formation (Jurassic-Cretaceous) (Love and Antweiler, 1973; Osterwald and others, 1966).

Copper, silver, and zinc mineralization has been recognized at several localities in the Overthrust Belt of western Wyoming. These deposits are reported in red beds of the Nugget Sandstone (Triassic(?)-Jurassic(?)), and also in the Wells Formation (Pennsylvanian-Permian), and in the Beckwith Formation (Jurassic-Cretaceous) (Love and Antweiler, 1973; Osterwald and others, 1966). The mineralization appears to be localized along fractures by reducing agents.

Copper deposits in the Nugget Sandstone are localized near the top of the formation where it is overlain by the Gypsum Springs member of the Twin Creek Limestone, and are intimately associated with green to white, altered sandstone as opposed to the dull red unaltered rock. The origin of the mineralization is not known and the lack of Precambrian and younger igneous rocks in this part of the Overthrust Belt would complicate a hydrothermal genesis. However, Love and Antweiler (1973) suggest that the metals may have been derived from metal-bearing oil, or possibly from the leaching of overlying tuffaceous sediments (long since removed by erosion) and localized by petroleum, or some other reducing agent. It is known that some oils in north central Wyoming are metaliferous, and that similar bleaching (or similar(?) alteration) occurs in oil-saturated Triassic red beds in central Wyoming (Love and Antweiler, 1973).

The largest mine in the Lake Alice District — the Griggs Mine (sec. 7, T.28N., R.117W.) — was developed by several adits and stull-type stoping in a bleached zone of the Nugget Sandstone (Figure 17). These occur over a vertical distance of more than 300 feet from top to bottom, suggesting the potential thickness of the ore body. Assays from old mine maps show a 4.5 foot mineralized zone in one tunnel which gave an average of 2.48 percent copper and 6 ounces per ton in silver. Recognizable ore minerals include malachite, azurite, chalcopyrite, and tenorite. Samples collected by Love and Antweiler (1973) ranged from 0.05 to 6.7 percent copper, a trace to 0.15 percent silver, a trace to 0.5 percent lead, and 0.02 to 0.81 percent zinc. Allen (1942) suggested that ore emplacement was structurally controlled. He reported that the ore occurred in shoots(?) developed along northeasterly and northwesterly fissure intersections. The fissures may have provided passageways for the reducing agents. Average assays reported by Allen contained 3.5 percent copper and 7.4 ounces of silver.

At the Ferney Gulch Mine (sec. 1, T.27N., R.118W.), also in the Lake Alice District, a selected sample of mineralized rock assayed 5 percent copper, a trace of silver, 2.6 percent zinc, 0.7 percent arsenic, 0.5 percent barium, 0.07 percent cobalt, 0.05 percent lead, and a trace of molybdenum (Love and Antweiler, 1973).

Native copper, impregnated in arkose at the base of the Fountain Formation (Pennsylvanian) 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).

URANIUM

Uranium in the Black Hills region of Crook County (Figure 20) 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 younger than the host rocks. Early studies indicated fairly late mineralization (40 to 130 thousand years ago), but more recent work suggests emplacement shortly after host rock deposition. Five different districts in Crook County have produced ore.

At Elkhorn Creek (T.56N., R.66W.), the host is the Fall River Formation. The Fall River in this district is 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 is reported as 28,850 tons.

Within the Aladdin area (T.54N., R.60W.), mineralization was found localized on the western flank of an anticline. Uranium occurred in both the Fall River and Lakota formations (Gray and Tennissen, 1953). Only 341 tons were shipped.

The Barlow Canyon District (T.54N. R.66W.) contains uranium ore in the Fall River Formation. Total production was more than 4,760 tons (Wilson, 1960a).

The mineralization in the Hulett Creek area (T.55N., R.67W.) was found in a 7,000 by 2,000 feet channel sandstone near the top of the Fall River Formation. Some additional ore was mined from the Lakota Formation (Robinson and Goode, 1957). Total ore production amounted to more than 595,000 tons.

The Lakota Formation hosted ore deposits in the Carlile area, T.52N., R.66W. (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 and stand out as rounded ledges protruding from Cretaceous shales. The apparent resistance of these bentonite ledges to erosion results from the support of siliceous shales in the footwall of the bentonite. The underlying shales are enriched in silica from the leaching of the overlying bentonite (Bates, 1969; Davis, 1965).

The more important bentonites are the 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) (Figure 15). Production totalled 3,584,700 tons.

GEOLOGIC SETTINGS FOR CENOZOIC MINERALIZATION

Geological environments in Wyoming during the Cenozoic era were favorable for the formation and deposition of uranium-bearing sandstone, lacustrine trona, uraniferous phosphate, oil shale, gold-bearing conglomerate, and porphyry copper-molybdenum systems.

The tectonic disturbances at the beginning of the Cenozoic resulted from continued uplift of the Rocky Mountain (Laramide) orogeny which had become active in Late Cretaceous time. The Late Cretaceous seas retreated as the uplift of infant ranges continued: continued uplift forced the Precambrian blocks up 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 intermontane basins were recipients of detrital debris fining in grain size toward the centers of the basins. In fluvial environments, large volumes of material were carried basinward to form thick sections of arkosic conglomerates, sandstones, and siltstones. In flood plains, finer sediments were deposited and extensive peat swamps developed (for discussions on Wyoming coal deposits, see Glass, 1978; 1980). 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 the late early Eocene. Basaltic and andesitic magma poured from fractures and accumulated in tremendous thicknesses of volcanic rock which now form the Absaroka Range. Ash falls were carried east.

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.

As time passed, uplifting along the Laramide Orogeny lessened and a number of intermontane lakes filled broad basins. Lake Gosiute, 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, with volcanic centers erupting in the Rattlesnake Hills of central Wyoming and intrusive activity in the Black Hills of northeastern Wyoming. During the mid-Tertiary, mineralized granodiorite stocks intruded the Absaroka volcanics. Near the end of the Tertiary, detrital sedimentation was much less intense, but volcanism in the Absarokas as well as new activity in the Leucite Hills in southwestern Wyoming and at Battle Mountain along the Wyoming-Colorado border added volcanic debris to the sediments.

CENOZOIC MINERAL DEPOSITS

Undoubtedly the most important Cenozoic mineral deposits include epigenetic uranium deposits in arkosic sediments and trona deposits in lacustrine sediments. Uranium was first mined between 1918 and 1922 in small tonnages at the Silver Cliff Mine in east-central Wyoming. In the early 1950's, several major uranium discoveries made in Tertiary sediments led to the development of Wyoming's uranium mining industry (Wilson, 1960a) (Figure 18).

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

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, strata-bound roll-front deposits, located at contacts between oxidized (altered) and reduced (unaltered) host rocks (Figure 19). The majority of the host rocks are fluviatile or are alluvial-fan type facies. Total uranium production in 1980 amounted to approximately 5,472,000 tons of ore.

Economic mineralization in the Gas Hills District (Figure 20) is restricted to the Puddle Springs Member of the Wind River Formation. The Puddle Springs is between 300 and 800 feet thick within the district, and is comprised of coarse-grained, arkosic sandstone 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 preparation; 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 fluvial 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 preparation) (Figure 21).

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 sandstone to an altered greenish-yellow sandstone. The primary ore mineral, uraninite, fills pore spaces, coats sand grains, and replaces 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 is found in eolian rather than fluvial sediments. Uranium in the Baggs

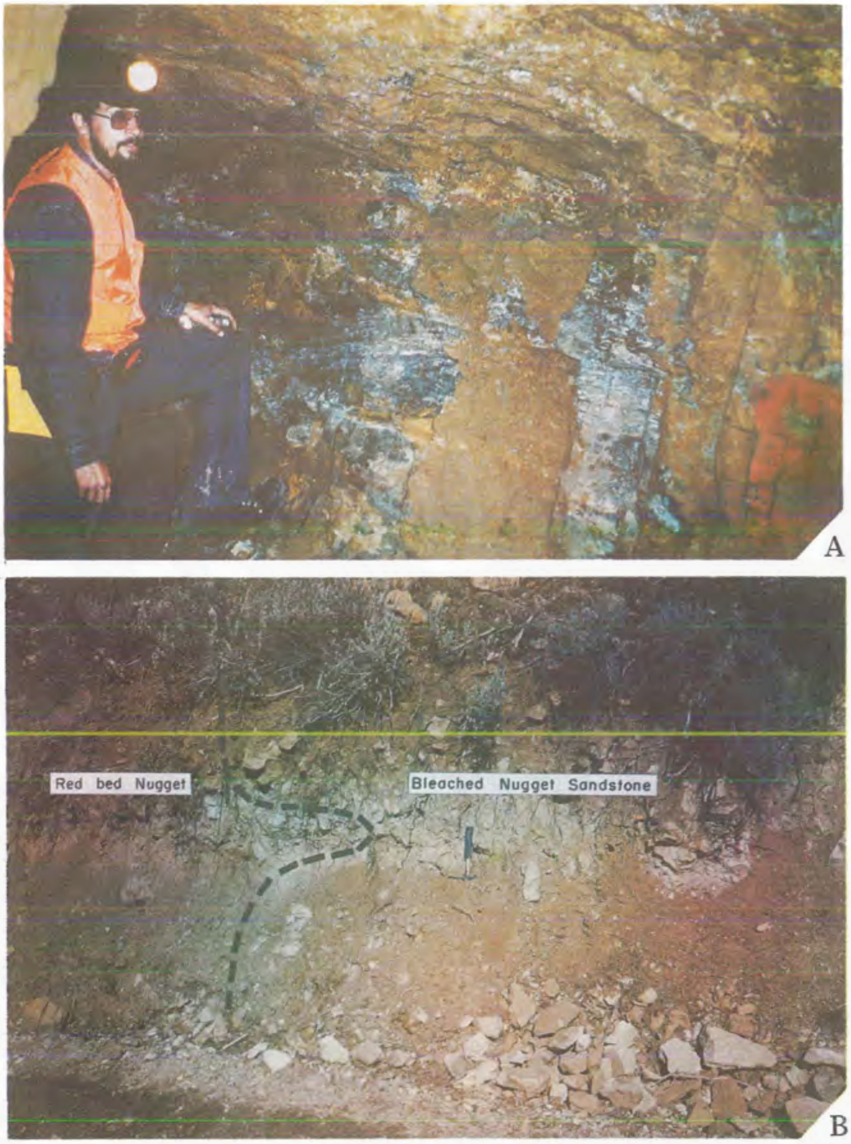

Figure 17. [Left] *(A) Copper mineralization inside the Griggs Mine. This deposit is suggested to be a red bed copper deposit. The copper mineralization may have been deposited by low-temperature solutions which resulted in the bleaching of the ferric-oxide-cemented sediments. The mineralization is believed to have been localized by a reducing agent (petroleum, bacteria, etc.). (B) Exposed cut on the side of the hill near the entrance to one of the Griggs adits. Left side (dark) is red hematite-stained sandstone, right side (light) is bleached white (iron converted to ferrous sulfide?). Photographs by J. Roberts and W.D.H.*

Figure 18. [Above] *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 in Tertiary sediments were found by J.D. Love of the U.S. Geological Survey. His discovery led to many discoveries in nearby basins. Photograph by W.D.H., 1978.*

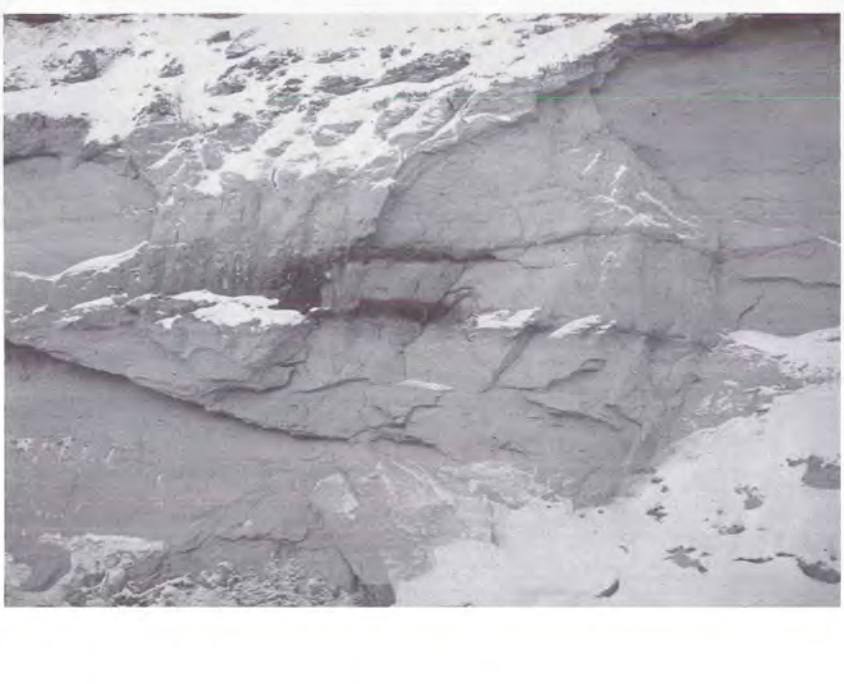

Figure 19. [Lower left] *Exposed uranium roll front in a wall of Pathfinder Mines Corporation's Shirley Basin Mine. The roll front forms the black, concentric feature in the center of the photograph. The oxidized sandstone lies to the right of the roll front, the reduced sandstone to left. Photography by W.D.H., 1977.*

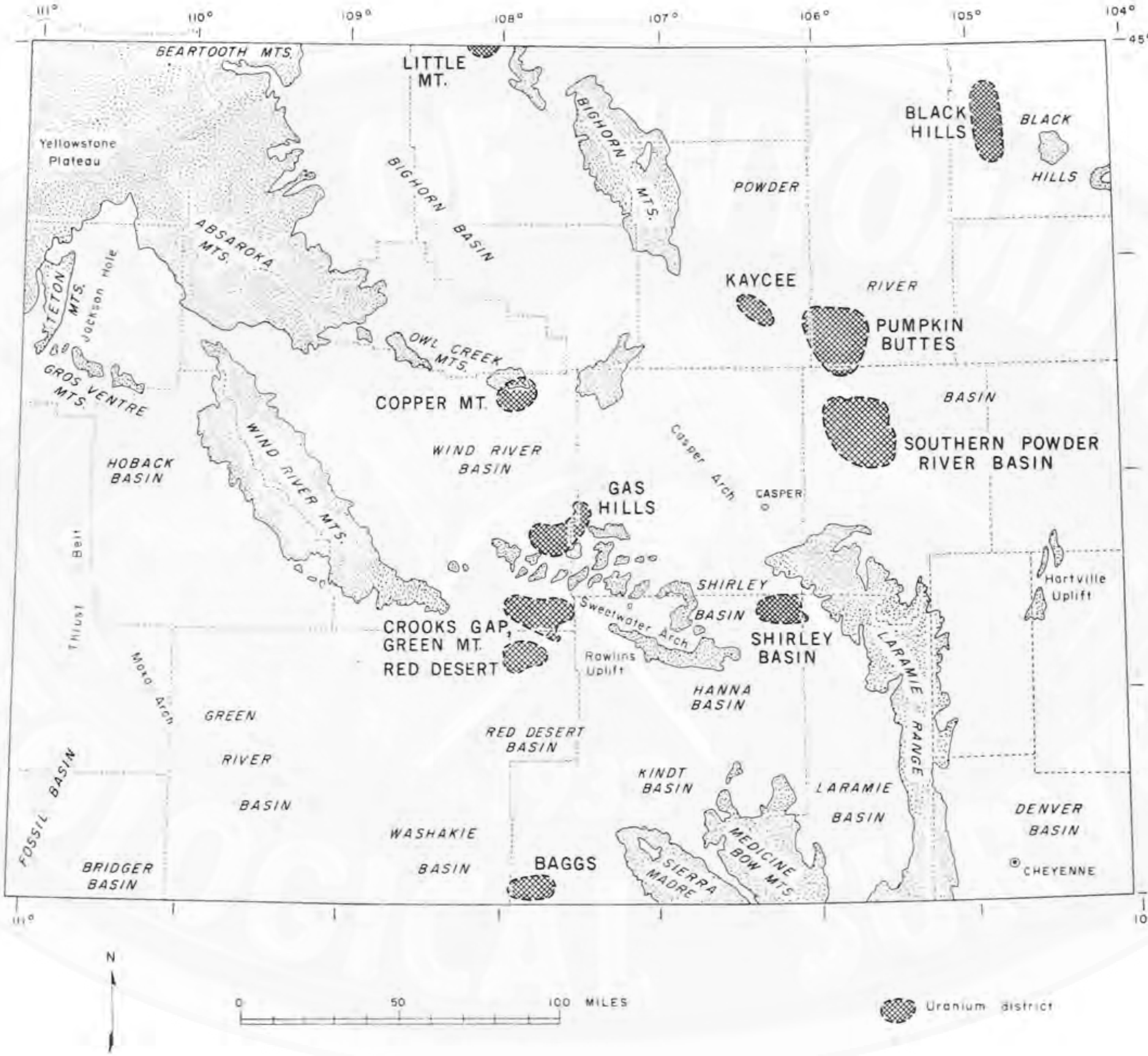

Figure 20. Location map of major active and inactive uranium districts (after Hausel and others, 1979).

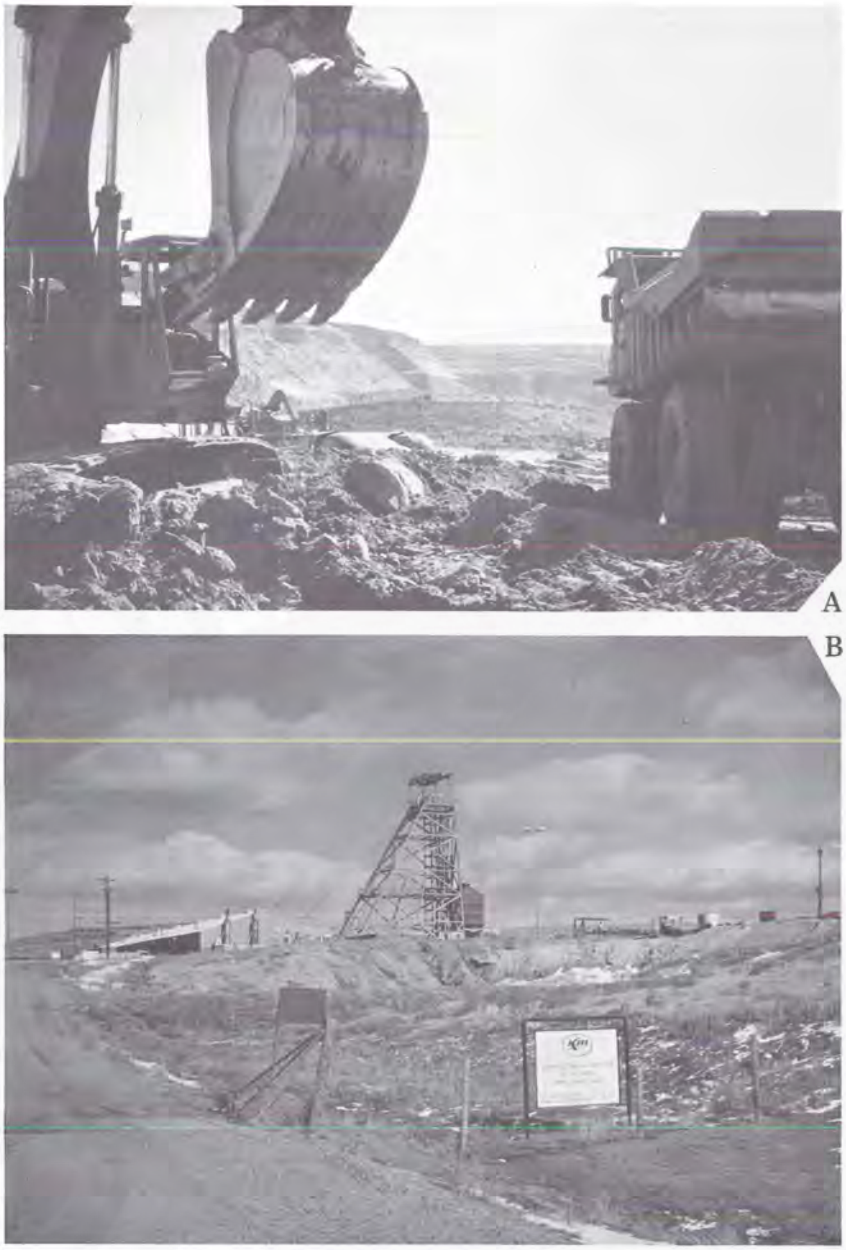

Figure 21. Uranium mines in the southern Powder River Basin. (A) Open pit mining at Exxon's Highland mine. (B) Headframe of Kerr-McGee's Bill Smith shaft. Photographs by W.D.H., 1979.

District occurs in Miocene sandstones of the Browns Park Formation. The Browns Park consists of a series of eolian, soft, friable, highly crossbedded 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 Urangesellschaft USA. Urangesellschaft 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 found in propylitically altered rocks and breccia zones and along fractures associated with 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 was deposited in a fluviatile-deltaic depositional environment and shows 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, as against 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 mines from 1954 to the present.

Uranium in the Red Desert area is found in arkosic sandstones in an alluial-fan complex in the Battle Spring Formation and as uraniferous lignites in the Wasatch Formation (Sherborne and others, 1979). Economic deposits mined from arenaceous hosts at Minerals Exploration Sweetwater Mine are low grade and average only about 0.038 percent uranium.

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 (Figure 15) (Culbertson, 1971).

The Wilkins Peak Member consists of beds of marlstone, claystone, limestone, tuff, mudstone, siltstone, sandstone, trona-halite, 77 persistent 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 FMC Corporation) (Burnside and Culbertson, 1979). More than 100 million tons of trona have now been extracted in the Green River Basin since mining began in 1946. The ore is mined from four underground mines (a fifth mine is under construction), predominantly by room-and-pillar methods (Hausel, 1978).

GOLD-BEARING CONGLOMERATE

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 (Figure 15).

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

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

Placer gold in northwestern Wyoming occurs in modern alluvial stream and terrace deposits as well as in quartzite conglomerates of Tertiary and Cretaceous age. 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, 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 22).

On Rocky Mountain Energy Company's property in the Washakie Basin, bedded zeolite occurs as light-green clinoptilolite, and is located under thin overburden in an area that extends for several miles (Figure 15) (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 (Figure 15) (Hausel, 1980a; Osterwald and others, 1966; Welch, 1974). Three districts in the county — Bear Lodge, Black Buttes, and Negro Hill–Mineral Hill (Figure 23) — have produced only minor ore tonnages in the past, and presently contain no active mines.

The Bear Lodge Mountains are formed from an uplifted Tertiary laccolithic intrusive. The sedi-

Figure 22. 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.D.H., 1980.

mentary rocks on the flanks of the uplift, ranging in age from Cambrian to Cretaceous, have been stripped off from its center, exposing the core of the alkalic intrusive complex. The intrusive phases have the compositions of syenite, monzonite, trachyte, and phonolite (Cox, 1945).

Two types of mineral commodities have been identified associated with the intrusive. These are fluorite and rare earth oxide deposits.

The fluorite mineralization, which is confined to the eastern flank of the mountains, occurs as metasomatic replacement deposits, as disseminations in sandstone, as silicious fluorite-bearing veins in the intrusive alkalic rocks, and as breccia filling along fault planes. Rare earth oxides are associated with iron-manganese veins and veinlets that fill fractures in monzonite and syenite prophyries.

Late Paleozoic sediments host scattered fluorite deposits. These sediments were intruded by Tertiary trachytic, syenitic, and monzonitic porphyries and by phonolite dikes. In places, the Pahasapa Formation (Mississippian) has been marbleized and replaced by fluorite. Overlying the Pahasapa Formation, the Minnelusa Sandstone (Pennsylvanian) contains dissemianted black fluorite grains in small zones surrounding a phonolitic sill.

Many of the fluorite deposits are described as massive replacements with interlayered sediments. The deposits are limited in tonnage and of low grade, with some localized rich lenses of fluorite assaying as high as 60 to 90 percent CaF_2. Silicious fluorite veins in intrusive rocks are as much as 2 feet wide in breccia zones. Only a small amount of rock has been mined from these prospects.

The rare earth oxides occur in iron-manganese veins that fill fractures in the host intrusive and in zones of intensely altered igneous rock.

Analytical reports of six samples gave 0.005 to 0.018 percent U_3O_8 and 0.20 to 12.99 percent REE (rare earth elements) (Osterwald and others, 1966). Drilling by the U.S. Bureau of Mines indicates that two claims (Claims No. 8 and No. 10) contain 4,000 tons of 3.9 percent REE and 40,000 tons of 1.5 percent REE.

Mineralization at Black Buttes is restricted to small replacement bodies in limestone. Lead, silver, and zinc reportedly replace Paleozoic limestone and fill breccias. A grab sample assayed 2 ounces per ton of silver and 5.7 percent zinc (Osterwald and others, 1966).

In the Negro Hill-Mineral Hill region, gold is the most important 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 (Figure 24). The intruded volcanics consist of more than 5,000 feet of layered laharic breccias, lava flows, flow breccias, and tuffs.

By the late Eocene(?) to early Oligocene(?), 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

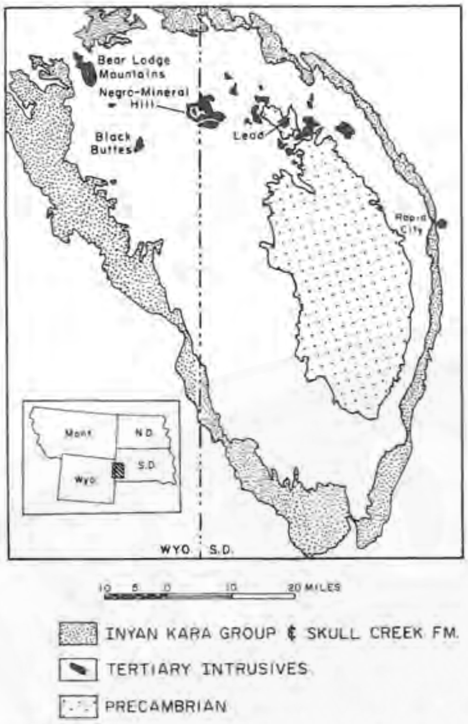

Figure 23. Map of mineral districts of the Black Hills area, showing locations of major Tertiary intrusives. After Welch, 1974.

orogenic belt (Fisher, 1972; Rouse, 1940) and northwest through Butte, Montana 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 stockworks, veins, disseminated mineralization, and alteration, all similar to the porphyry copper deposits described by Creasey (1966), Hollister (1978), and Lowell and Gilbert (1970).

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 a mineralized intrusive (Fisher, 1972; Wilson, 1964).

In the mineralized area, 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 are 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 argentiferous 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 intrusives 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,

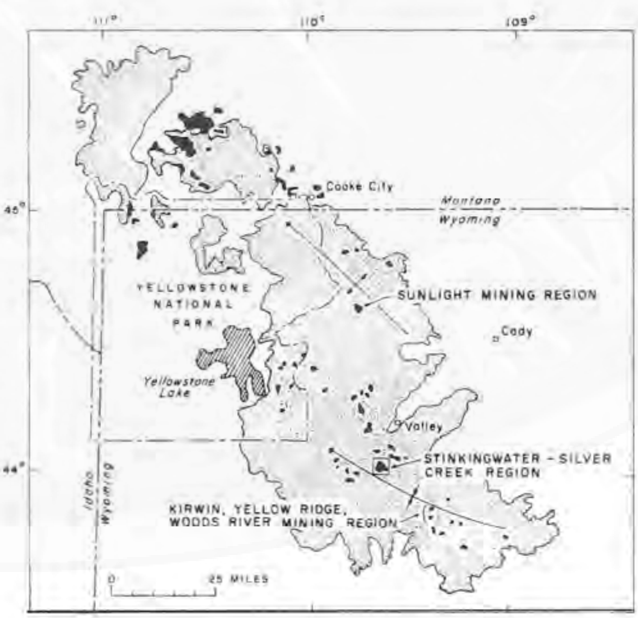

Figure 24. Location of the Absaroka porphyry copper-molybdenum deposits in northwestern Wyoming. After Fisher (1972) and Wilson (1955).

Table 1. Characteristics of the Absaroka porphyry mineralized deposits.

District or Region	Intrusion close to ore	Intruded rock	Structural trends	Alteration zones	Supergene enriched zones
KIRWIN	Rhyolitic tuff(?) (Nowell, 1971)	Wiggins Fm. (andesites) (Wilson, 1964)	northwesterly & northeasterly striking joints and fissures (Wilson, 1964)	propylitic phyllic potassic argillic(?) (Nowell, 1971)	minor? (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 porphyry, hornblende andesite (Fisher et al., 1977)	Wiggins Fm. (andesites) (Fisher et al., 1977)	no available data	propylitic phyllic potassic (Fisher et al., 1977)	no available data
SILVER CREEK	dacite porphyry, rhyodacite porphyry (Fisher et al., 1977)	Wapiti Fm., Wiggins Fm., Trout Peak trachyandesite (Fisher et al., 1977)	well developed fractures trend from N.35°E. to N.80°W. (Fisher et al., 1977)	propylitic phyllic potassic (Fisher et al., 1977)	no available data
STINKINGWATER	Needle Mtn. granodiorite, Crater Mtn. dacite (Fisher, 1972)	Trout Peak trachyandesite, Wiggins Fm., Wapiti Fm. (Fisher, 1972)	Northwest and east to northeast fracture sets (Fisher, 1972)	propylitic phyllic potassic argillic (Fisher, 1972)	present maximum thickness at least 200 feet (Fisher, 1972)
SUNLIGHT	syenite (Dreier, 1967; Rich, 1974)	Wapiti Fm. (Nelson & Prostka, 1980)	dominant set of fractures trend N.30°W. (Dreier, 1967)	propylitic potassic argillic (Dreier, 1967; Rich, 1974)	no available data

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 potassic alteration zone is reported in all of the mineralized regions except 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 the Kirwin (Nowell, 1971) mineralized areas.

All these mineralized areas of porphyry copper-molybdenite mineralization lie, in general, either 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. Many of these mineralized regions were prospected in the late 1800's and early 1900's, and renewed interest did occur in the 1970's. Recently, the U.S. Bureau of Mines (Rosenkranz and others, 1979) reported that the Kirwin area contained a resource of at least 70 million short tons of 0.75 percent copper. 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 25). In 1980, Morrison-Knudsen and the 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 Railroad totalled 74,900 tons.

Figure 25. Sand and gravel operations along the Laramie River near Laramie. Each year the sand and gravel industry produces four to five million tons of material. Photograph by W.D.H., 1977.

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