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General Geologic Setting and Mineralization of the Porphyry Copper Deposits, Absaroka Volcanic Plateau, Wyoming

by W. Dan Hausel

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GENERAL GEOLOGIC SETTING AND MINERALIZATION OF THE PORPHYRY COPPER DEPOSITS, ABSAROKA VOLCANIC PLATEAU, WYOMING

BY W. DAN HAUSEL[1]

INTRODUCTION

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

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

Mineralization associated with these volcanic centers generally occurs as disseminations and stockworks in intensely altered rock, and in fractures and veins that transect both the mineralized intrusive and the vent-series wall rocks. The effect of hydrothermal alteration processes has been to produce zoned mineralization and alteration. Generally, copper, molybdenum, and trace gold occupy the central portion of the complex. These metals give way to zinc, lead, and silver ores laterally away from the center of the intrusive complex.

Both mineralized and barren intrusive centers are the source of the great pile of volcanic rock that forms the Absaroka Mountains. The Absaroka volcanics extend over a surface area of more than 8,000 square miles and compositionally consist of calc-alkaline flows, flow breccias, breccias, and reworked sedimentary facies. A small volume of flows in the northern Absarokas is shoshonitic.

The Absaroka volcanics form a northwesterly trend of igneous rock along the eastern border of Yellowstone Park that extends north into Montana (Figure 1). The trend of the volcanics is assumed to be structurally controlled by some deep-seated fracture system.

Overviews of the Absaroka volcanic field have been published by Chadwick (1970), Hague (1899), Parsons (1939), Rouse (1937), and Wilson (1971). Several excellent papers and theses are available which describe the known mineralized centers. Drier (1967), Nelson and others (1980), Osterwald and others (1966), Parsons (1937), Pedersen (1968), and Rich (1974) discuss the geology and mineralization of the Sunlight area. The Eagle Creek region was the subject of a thesis by Galey (1971). Mineral deposits and alteration were examined by Fisher (1972) in the Stinkingwater region. The mineralized centers in the

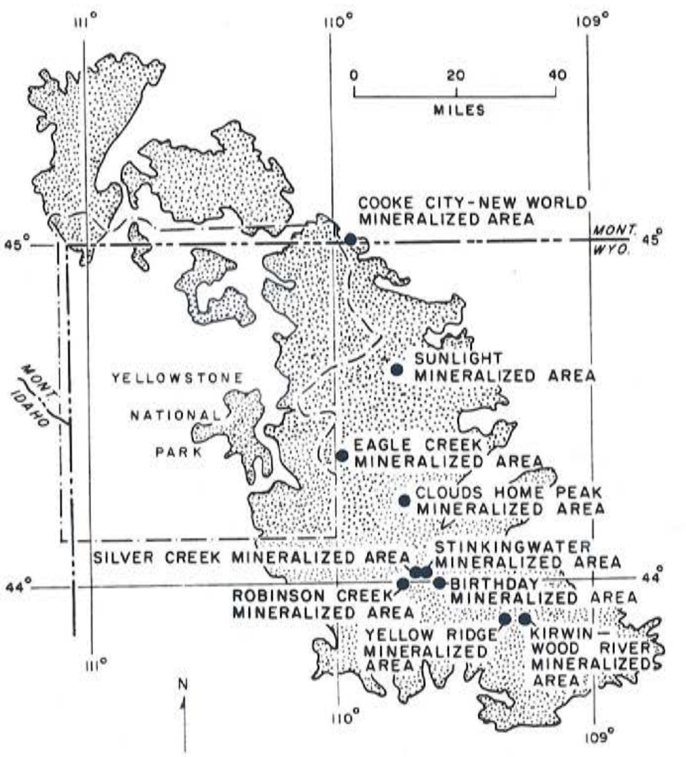

Figure 1: Location map of the known porphyry mineralized areas of the Absarokas.

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Kirwin-Wood River area were mapped and summarized by Wilson (1954, 1960, 1963, 1964a, 1964b, 1975, 1982), discussed by Nowell (1971), and Osterwald and others (1966). The Cooke City deposits are the subject of Butler (1965), Lovering (1929), Nelson and others (1980), and Reed (1950). The Silver Creek and Yellow Ridge porphyry centers were briefly examined by Fisher and others (1977); and Fisher and Antweiler (1980) conducted reconnaissance surveys of mineralization and alteration associated with the Robinson Creek, Birthday, and Clouds Home Peak porphyry systems. More recently, an abstracted review of the Absaroka mineralized centers was published by Hausel (1982).

This paper is written as a brief overview of the porphyry copper deposits of the Absaroka volcanic plateau, and is written to hopefully alleviate a few editorial errors printed in Hausel (1981). The paper is primarily a summarzation of the previous listed published literature, with supportive cursory field reconnaissance. Essentially, all of the following discussions are abstracted from the published literature, and the interested reader will want to refer to the bibliography.

THE ABSAROKA VOLCANIC FIELD

The Absaroka volcanic field covers more than 8,000 square miles of surface area in northwestern Wyoming and southern Montana. The bulk of the field consists of calc-alkaline andesites with lesser basaltic and dacitic rock. These occur as flows, flow breccias, and breccias that grade into volcaniclastic sediment in the southern half of the field; the northern half of the field is formed predominantly of volcanic flows and related igneous rocks. A small volume of the Absaroka field (about 10%) is formed of potassic alkalic mafic flows of the shoshonite suite. The genesis of these ultra-potassic flows is discussed by Prostka (1973), Carmicheal and others (1974, p. 511-517 and 657-659), and Turner and Verhoogen (1960, p. 235-256), and their genesis will not be pursued here.

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

The Absaroka volcanics and volcaniclastics are termed the Absaroka Supergroup. Generally, the Absaroka Supergroup averages greater than 5,000 feet thick (Smedes and Prostka, 1972), and in places is as much as 6,500 feet thick (Wilson, 1964b). Facies relationships and thicknesses of volcanic-rich strata along the east edge of the field indicate that the Absaroka volcanics, at one time, may have extended across much of the Bighorn Basin (Love, 1939).

The Absaroka Supergroup is divided into three groups: from oldest to youngest — the Washburn, Sunlight and Thorofare Creek groups (Figure 2). The Washburn

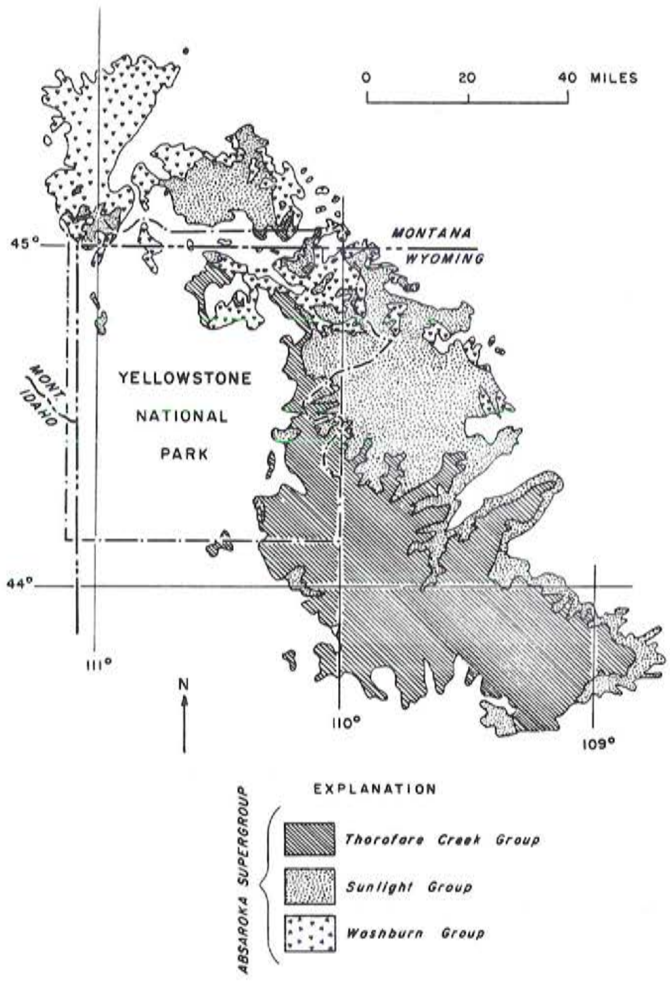

Figure 2: Generalized geologic map of the Absaroka Supergroup (after Smedes and Prostka, 1972).

Group is restricted in the north of the field and represents the oldest volcanic rocks. It is overlapped in most places unconformably by the Sunlight and Thorofare Creek groups. Nearly everywhere, the Thorofare Creek Group overlies the Sunlight Group.

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

Each of the three groups is subdivided into formations. Stratigraphic descriptions of the formations are presented by Smedes and Prostka (1972) and will not be discussed here.

PORPHYRY COPPER MODELS

Two general porphyry copper models are recognized by most exploration geologists, and these are the Lowell and Guilbert (1970) Model, and the Diorite Model (Hollister, 1974). Nearly all of the Absaroka porphyry systems are of the Lowell and Guilbert (1970) type, although Dioritic-type porphyry systems are also apparently present.

Very generally, the Lowell and Guilbert Model requires the mineralizing intrusive, or intrusives, to be oversaturated with silica. Intrusive rocks are calc-alkaline plutons in the granodiorite-quartz monzonite range. Alteration zones produced in this model include all or some of the following alteration halos progressing outward from the mineralized intrusive: (1) a potassic core (secondary orthoclase-biotite); (2) a phyllic zone (quartz-sericite-pyrite); (3) an argillic zone (kaolinite-illite-montmorillonite-pyrite) and an outer propylitic zone (epidote-chlorite-calcite). Hypogene disseminated copper sulfides are commonly developed at or near the interface of the potassic and phyllic zones and the greater amounts of pyrite are more commonly enclosed by the phyllic zone (Lowell and Guilbert, 1970; Titley, 1982; Beane and Titley, 1981; Hollister, 1978).

The Diorite Model encompasses quartz-free plutons. Included are alkalic suites as well as calc-alkaline diorite to syenite stocks. Alteration zones developed within the Diorite Model generally contain a potassic core assemblage with either biotite or chlorite dominant. The phyllic and argillic hydrothermal altered zones are generally absent or poorly developed. The potassic zone generally abuts against a propylitic zone. Pervasive pyrite generally is confined to the potassic zone (Hollister, 1974, 1978). Porphyry deposits occurring entirely in andesite and diabase are likely to have alteration expressions similar to the Diorite Model (Hollister, 1978).

The Lowell and Guilbert (1970) Model is charateristic of essentially all of the Absaroka porphyry deposits such as the Kirwin mineralized area, although none of the porphyry districts other than possibly Kirwin, Stinkingwater and Sunlight Basin have been studied in sufficient detail to assign a characteristic model with confidence. Both the Kirwin and Stinkingwater appear to more closely approximate the Lowell and Guilbert Model, and the Sunlight Basin complex has similarities to the Diorite porphyry model.

THE MINERALIZED CENTERS

W. H. Wilson was the first to recognize the potential of the vent areas in the Absarokas for porphyry copper deposits. These mineral deposits in the Absarokas (Figure 1) occur as: (1) disseminated and stockwork mineralization in intensely altered stocks or composite stocks, and, at a few localities, in country rock adjacent to mineralized stocks; (2) fracture-filled veins and veinlets extending outward from the mineralized centers; (3) fracture-and fissure-filled veins and replacement deposits hosted by Paleozoic carbonates (recognized only in the New World district); (4) supergene enriched deposits; and (5) placer gold deposits below porphyry districts.

Mineralization of the stocks is associated with hydrothermal alteration of varying intensity (Table 1). All of the districts exhibit widespread deuteric propylitic alteration. Near the intrusive centers, the deuteric alteration takes on the effects of hydrothermal propylitic alteration. Generally, the presence of veins or veinlets of calcite, epidote, chlorite and pyrite in the propylitically altered rock signifies that the deuterically altered rock has been overprinted by hydrothermal alteration.

Phyllic alteration (quartz-sericite-pyrite) is recognized near disseminated copper mineralization at all of the known mineralized areas except the Sunlight Basin, where this alteration halo is absent. Argillic alteration has been identified at several of the intrusive centers, although in most cases, the described alteration appears to be supergene rather than hypogene alteration. Potassic alteration has been identified in several of the districts, although the potassic halo is generally poorly defined.

Kirwin - Wood River Mineralized Area

The Kirwin - Wood River district contains three mineralized centers and north-northwest trending veins. Each of the three centers exhibits varying degrees of copper-molybdenum mineralization and hydrothermal alteration.

Table 1: Characteristics of the Absaroka porphyry copper deposits.

Deposit	Intrusion close to ore	Intruded rock or host* rock	Structural trends
Kirwin	rhyolitic (felsic) tuff and breccias (Nowell, 1971)	Wiggins Fm. andesites (Thorofare Creek Group) (Wilson, 1964b)	northwesterly and northeasterly striking joints and fissures (Wilson, 1964b)
Meadow Creek	Meadow Creek granodiorite (Wilson, 1975)	Wiggins Fm. andesites (Thorofare Creek Group) (Wilson, 1975)	intersected by N-S and E-W trending faults. NW trending veins. Radial dike pattern. (Wilson, 1960, 1975)
Brown Mtn.	Brown Mtn. granodiorite (Wilson, 1964b)	Wiggins Fm. andesite (Thorofare Creek Group) (Wilson, 1964b)	N-NW trending veins along Galena Ridge. Joint sets in intrusion: EW; NE-SW; and NW-SE. (Wilson, 1960)
Silver Creek	dacite - and rhyodacite-porphyry (Fisher and others, 1977)	Wiggins Fm. (Thorofare Creek Group), Trout Peak Trachy-andesite and Wapiti Fm. (Sunlight Group) (Fisher and others, 1977)	well developed fractures trend N35°E to N80°W (Fisher and others, 1977)
Yellow Ridge	granodiorite, diorite, andesite porphyry, hornblende-andesite porphyry (Fisher and others, 1977)	Wiggins Fm. (Thorofare Creek Group) (Fisher and others, 1977)	no data
Birthday	granodiorite-dacite (Fisher and Antweiler, 1980)	Wiggins Fm. (Thorofare Creek Group) (Fisher and Antweiler, 1980)	NW-trending stockworks and dikes, and NE-trending dikes. (Fisher and Antweiler, 1980)
Robinson Creek	rhyodacite-dacite (Fisher and Antweiler, 1980)	Wiggins Fm. (Thorofare Creek Group) (Fisher and Antweiler, 1980)	Major fracture zones trend N20°W to N60°W. Less developed fractures trend NE. (Fisher and Antweiler, 1980)
Clouds Home Peak	dacite, rhyodacite, granodiorite, and quartz monzonite (Fisher and Antweiler, 1980)	Wiggins Fm. (Thorofare Creek Group) (Fisher and Antweiler, 1980)	NE and NW trending dikes and faults. (Fisher and Antweiler, 1980)
Eagle Creek	latite porphyry (Galey, 1971)	Langford Fm. (Thorofare Creek Group) and Trout Peak Trachy-andesite (Sunlight Group) (Galey, 1971)	N-NW and NE striking joints and N32°E and N64°W quartz vein trends. (Galey, 1971)
Stinking-water	Needle Mtn. granodiorite and Crater Mtn. dacite (Fisher, 1972)	Wiggins Fm. (Thorofare Creek Group), Trout Peak Trachy-andesite, and Wapiti Formation (Sunlight Group) (Fisher, 1972)	NW, and E to NE trending fracture sets. (Fisher, 1972)
Sunlight	syenite (Drier, 1967; Pedersen, 1968; Rich, 1974)	Wapiti Fm. (Sunlight Group) (Nelson and others, 1980)	N39°W fracture set and dominant radial dike pattern. (Nelson and others, 1980)
Cooke City	Henderson Mtn. monzonite porphyry, and Goose Lake syenite (Lovering, 1929)	*Paleozoic sediments (Pilgrim Limestone and Gros Ventre Fm. host) (Elliott, 1980b)	————

Alteration types	Critical alteration assemblages	Major sulfides	Supergene enriched zones
propylitic argillic-phyllic potassic (Nowell, 1971)	quartz, calcite, epidote, montmorillonite. sericite, mixed layer illite-montmorillonite, quartz, biotite, kaolinite, chlorite, pyrite. orthoclase, quartz, sulfide veinlets. (Nowell, 1971)	chalcopyrite molybdenite pyrite (Wilson, 1964b)	chalcocite, digenite, covellite blanket (Wilson, 1964b)
propylitic phyllic (Wilson, 1975)	epidote, chlorite, calcite. quartz, sericite, pyrite. (Wilson, 1975)	chalcopyrite pyrite molybdenite (?) (Wilson, 1975)	no data
propylitic (Wilson, 1960)	pyrite, calcite, chlorite, epidote, sericite. (Wilson, 1960)	chalcopyrite pyrite	no data
propylitic phyllic potassic (Fisher and others, 1977)	chlorite, calcite, epidote. quartz, sericite, pyrite. quartz-potassium feldspar veinlets and secondary biotite and magnetite. (Fisher and others, 1977)	chalcopyrite molybdenite bornite pyrite (Fisher and others, 1977)	no data
propylitic phyllic potassic (Fisher and others, 1977)	chlorite, calcite, epidote. quartz, sericite, pyrite. quartz-potassium feldspar veinlets and secondary biotite and magnetite. (Fisher and others, 1977)	pyrite, chalcopyrite, bornite (?), molybdenite (?) (Fisher and others, 1977)	no data
propylitic phyllic potassic (Fisher and Antweiler, 1980)	chlorite, calcite, epidote, saussurite, pyrite. sericite, pyrite, quartz. actinolite/tremolite, K-feldspar, magnetite, quartz, chalcopyrite veinlets. (Fisher and Antweiler, 1980)	pyrite chalcopyrite (Fisher and Antweiler, 1980)	no data
propylitic phyllic argillic (supergene) (Fisher and Antweiler, 1980)	calcite, epidote, chlorite. quartz, sericite, pyrite. clay minerals. (Fisher and Antweiler, 1980)	pyrite chalcopyrite (Fisher and Antweiler, 1980)	no data
propylitic phyllic (Fisher and Antweiler, 1980)	epidote, calcite, chlorite, saussurite. quartz, sericite, pyrite. (Fisher and Antweiler, 1980)	pyrite chalcopyrite (Fisher and Antweiler, 1980)	no data
propylitic phyllic(?) potassic (?) (Galey, 1971)	chlorite, calcite, epidote, sericite. sericite, calcite, clay, chlorite, quartz. pyrite, K-feldspar (?). (Galey, 1971)	pyrite chalcopyrite galena, sphalerite (Galey, 1971)	none
propylitic phyllic potassic argillic (supergene) (Fisher, 1972)	chlorite, sericite, magnetite, calcite, epidote. quartz, sericite, pyrite. clay minerals. biotite, sericite, quartz. (Fisher, 1972)	chalcopyrite pyrite molybdenite chalcocite (Fisher, 1972)	100 to 200 foot thick zone (Fisher, 1972)
propylitic potassic argillic (Elliott, 1980a)	epidote, calcite, chlorite. K-feldspar, sericite, clay, calcite, quartz. clay minerals, chlorite. (Rich, 1974; Pedersen, 1968; Drier, 1967)	chalcopyrite (Elliott, 1980a)	minor covellite, chalcocite, malachite (Elliott, 1980a)
silicification dolomitization (Elliott, 1980b)	dolomite, quartz, calcite, sulfides. (Butler, 1965)	pyrite, chalcopyrite, galena (Elliott, 1980b)	no data

The Kirwin - Wood River area is located in the southern Absaroka Mountains near the headwaters of the Wood River, 33 miles southwest of Meeteetse — the nearest town. Early development of the district took place near the turn of the century. More than 12,000 feet of drifts, shafts and adits were developed in veins, attempting to intersect ore shoots. Production was limited to one carload of ore reported to yield a net value of $65 a ton after smelter and transportation charges were deducted (Hewett, 1912).

The three intrusive complexes (Kirwin, Brown Mountain grandiorite, and Meadow Creek granodiorite) penetrate volcanics of the Wiggins Formation (Eocene) (Figure 3). The Wiggins Formation is one of a group of formations belonging to the Thorofare Creek Group (Smedes and Prostka, 1972). In this area, the Wiggins Formation forms a series of deuterically propylitized hornblende- biotite and pyroxene andesite porphyry flows, tuffs, breccias, and volcaniclastic sediments. The vent facies layered volcanics have been domed, hydrothermally altered, and radially fractured. Andesite porphyry dikes occupy radial fractures, as well as the dominant north-northwesterly structural trend recognized throughout the Kirwin - Wood River area. With a few exceptions, mineralized veins are localized in north-northwesterly fractures and predominantly are lead-silver-zinc veins. In the Kirwin mineralized-altered zone on the northern flank of Bald Mountain, the veins are copper-molybdenum dominant.

Brown Mountain Granodiorite. The Brown Mountain granodiorite is the least mineralized of the three intrusive complexes (Figure 3). The intrusive consists of fine- to medium-grained equigranular granodiorite grading into porphyritic phases near its northern margin. Hydrothermal alteration is expressed as weak propylitization with disseminated pyrite. Although the strongest manifestations of mineralization are north-northwesterly trending veins along Galena Ridge to the north of the intrusion (Wilson, 1960), it is not known if these veins are an expresssion of the Brown Mountain granodiorite or of the Kirwin mineralized complex (Nowell, 1971). Three prominent joint trends: (1) east-west; (2) northeast-southwest; and (3) northwest-southeast have been measured in the central portion of the intrusive (Wilson, 1960).

Meadow Creek Granodiorite. The Meadow Creek granodiorite (Figure 3) is a composite of at least two separate intrusives that vary from granite to diorite and average as granodiorite. The older granodiorite (forming the western third of the intrusive mass) is propylitized, weakly pyritized, and relatively unmineralized. The later granodiorite (on the east) is propylitized with more intense alteration along two elongated zones (Figure 3). The

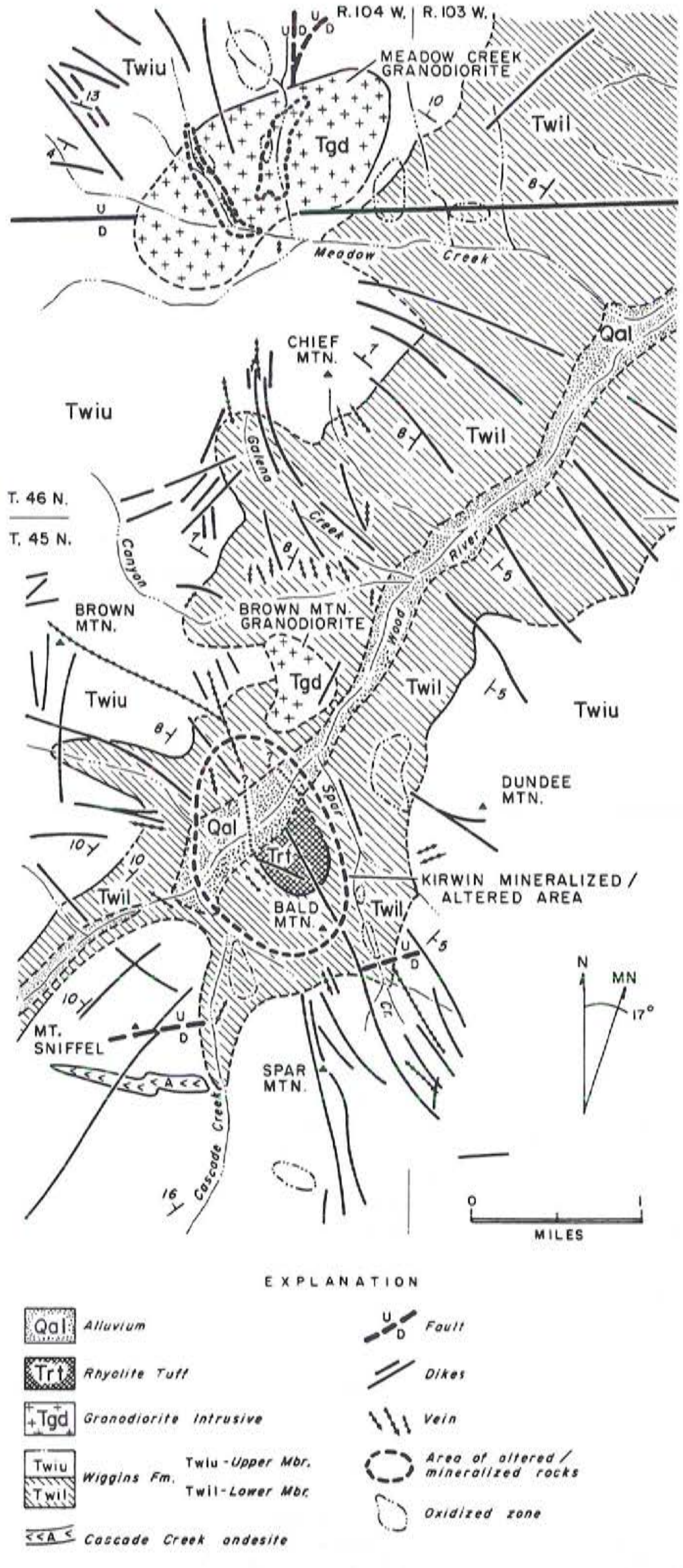

Figure 3: Generalized geological map of the Kirwin - Wood River area (Modified from Wilson, 1964b, 1975; Nowell, 1971).

intensely altered zone in the eastern portion of the complex extends across the intrusive along the projected trend of the north-south fault, and is delineated by phyllic alteration with disseminated copper mineralization. A second intensely altered zone is localized along the contact between the two granodiorite intrusives. This zone is outlined by intense silicification, iron-staining, and disseminated pyrite.

Spotty chalcopyrite and malachite occur as disseminations and as fracture fillings in limited exposures in both the altered granodiorite and adjacent Wiggins Formation. Other expressions of mineralization include copper, lead, and molybdenum geochemical anomalies within the intrusive, and mineralized quartz veins located both north and south of the intrusive. These veins occur as galena (argentiferous), sphalerite, tetrahedrite, minor pyrite and chalcopyrite mineralization in quartz-carbonate gangue (Wilson, 1975).

The Meadow Creek granodiorite is located at the intersection of two faults. The emplacement of the intrusive complex undoubtedly was controlled by this intersection. Dikes form rough radial patterns around the intrusive, and vein mineralization occurs in a north-northwest trending zone between the Brown Mountain and Meadow Creek intrusives (Wilson, 1964b; 1975).

Kirwin. The Kirwin mineralized area, located on the northwest flank of Bald Mountain, is expressed by a rough oval-shaped intense zone of hydrothermal alteration (Figure 3). The mineralized area is associated with a volcanic vent complex with exposures of intrusive rhyolitic tuff breccia (Wilson, 1964b; Nowell, 1971). Brecciation appears more commonly along the edge of the vent.

This mineralized area exhibits hydrothermal alteration with increasing intensity toward the center of alteration. Outside of the alteration zone, Wiggins Formation andesites are deuterically altered and exhibit propylitic alteration products — calcite, chlorite, and clays. Within 1,500 feet of the mineralized center, Wiggins andesites exhibit hydrothermal propylitic alteration characteristics and, in addition to the typical alteration minerals — quartz, calcite, epidote, and montmorillonite, these rocks contain chalcopyrite-bearing quartz-calcite veinlets and disseminated chalcopyrite blebs. Nearer to the volcanic center, alteration assemblages are more characteristic of argillic and phyllic hydrothermal alteration. Major alteration products include sericite, mixed-layer illite-montmorillonite, quartz, and biotite with lesser kaolinite and chlorite. Epidote and calcite are nonexistent in this zone.

The potassic zone is not well-defined, but is suggested by the presence of secondary orthoclase with quartz and veinlet sulfides. This zone lies near the mineralized center (Nowell, 1971).

Drill hole data in the Kirwin area show stockwork mineralization of pyrite, chalcopyrite and molybdenum. A secondary enriched blanket of chalcocite, digenite and covellite overlies a portion of the stockworks, which in turn, is overlain by a barren leached cap (Wilson, 1964b). Veins in the altered area are pyrite-chalcopyrite-molybdenum-quartz veins (Wilson, 1960).

The U.S. Bureau of Mines reports that the Kirwin mineralized-altered area at Bald Mountain, hosts a resource of at least 70 million short tons of 0.75 percent copper (Rosenkranz and others, 1979).

Yellow Ridge

The Yellow Ridge area lies within the boundaries of the Francs Peak 7½-minute quadrangle approximately 22 miles from the end of the Greybull River Road. A pack trail follows the Greybull River to the base of Yellow Ridge. The intrusive is also accessible from the Kirwin mineralized area. From Kirwin, the Greybull River trail crosses Greybull Pass and lies within three miles west-northwest of Kirwin.

Two stocks crop out through Wiggins breccias and flows at Yellow Ridge (Wilson, personal comm., 1982). These are rhyolite and a composite intrusive formed of granodiorite to diorite, andesite porphyry, and hornblende andesite porphyry (Figure 4). Much of the mineralization is associated with the andesite porphyry (dike?) although the other intrusive masses are weakly mineralized.

A narrow (200 to 300 feet) mineralized zone is exposed along a 2,500 feet northeasterly trend in the southeastern part of the stock. Malachite is abundant and occurs as fracture coatings and as disseminated grains. Pyrite, and lesser chalcopyrite, bornite(?) and molybdenum(?) also are found in the mineralized zone.

Hydrothermal alteration consists of an outer propylitic zone that includes the intrusive margin and adjacent extrusive rocks. Near the intrusive center, propylitic minerals grade into phyllic altered rock, and near heavily mineralized zones, potassic altered rock predominates (Fisher and others, 1977).

Stinkingwater Mineralized Area

The Stinkingwater mineralized area lies near the confluence of Needle Creek and the South Fork of the Shoshone River (sec. 18, T.47N., R.106W.) near the center of the southern Absaroka volcanic field. Layered, per-mineral, volcanic rocks in the district include, from oldest to youngest: the Wapiti Formation, the Trout Peak Trachyandesite, and the Wiggins Formation. These are composed principally of basalt and andesite flows, volcanic breccias and flow breccias, and are intruded locally by the

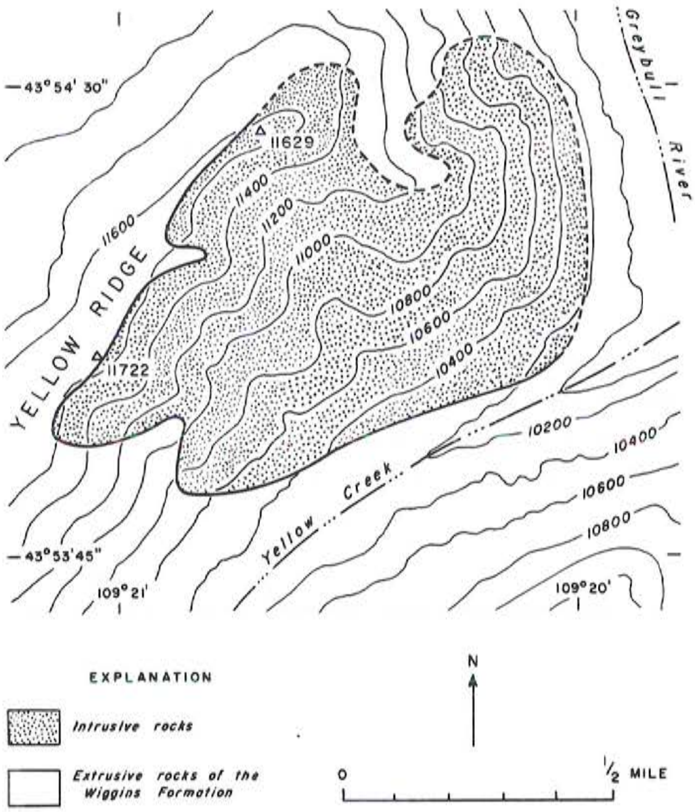

Figure 4: Sketch map of the Yellow Ridge intrusive (after Fisher and others, 1977).

Needle Mountain granodiorite and Crater Mountain dacite and numerous dikes which extend outward from the intrusive complex in a radial pattern (Figure 5). The Crater Mountain dacite intrudes the Needle Mountain granodiorite (Fisher, 1967, 1972).

The layered volcanic rocks adjacent to the intrusive complex are slightly domed and dip gently (maximum of 10°) away from the intrusive center (Fisher, 1972; Osterwald and others, 1966). Two major lineaments are recognized in the district; these trend northwest and east to northeast, and intersect at the intrusive complex. These fracture sets probably controlled the localization of the intrusive and the associated hydrothermal solutions.

Mineralization in the district includes an altered area (approximately three-quarters of a square mile) of disseminated copper-molybdenum near the southwestern edge of the intrusive complex. The greater mineralization is associated with a zone of intense hydrothermal alteration centered in the Crater Mountain dacite; the Needle Mountain granodiorite is poorly mineralized except along the northern edge of Needle Creek. All of the outcrops in the mineralized area are highly fractured and bleached, and are altered to varying degrees. Narrow, steeply dipping veins occur near, and, in places, as much as a mile away from the intrusive complex.

Chalcopyrite is the major disseminated ore mineral in the intensely altered zone followed in abundance by molybdenite and minor bornite. Beyond the central chalcopyrite-molybdenite zone, pyrite is more dominant and is associated with low copper-molybdenum values. Chalcopyrite and molybdenite also occur in narrow quartz veinlets and coat fractures in the area of disseminated sulfide minerals.

Vein mineralization extends outward from the altered mineralized zone for a few yards, and, in places, for nearly a mile. The veins are commonly one to two inches wide and reach a maximum of nearly one foot in width locally. These veins contain galena, chalcopyrite, sphalerite, pyrite, and minor arsenopyrite and tetrahedrite in quartz, calcite,

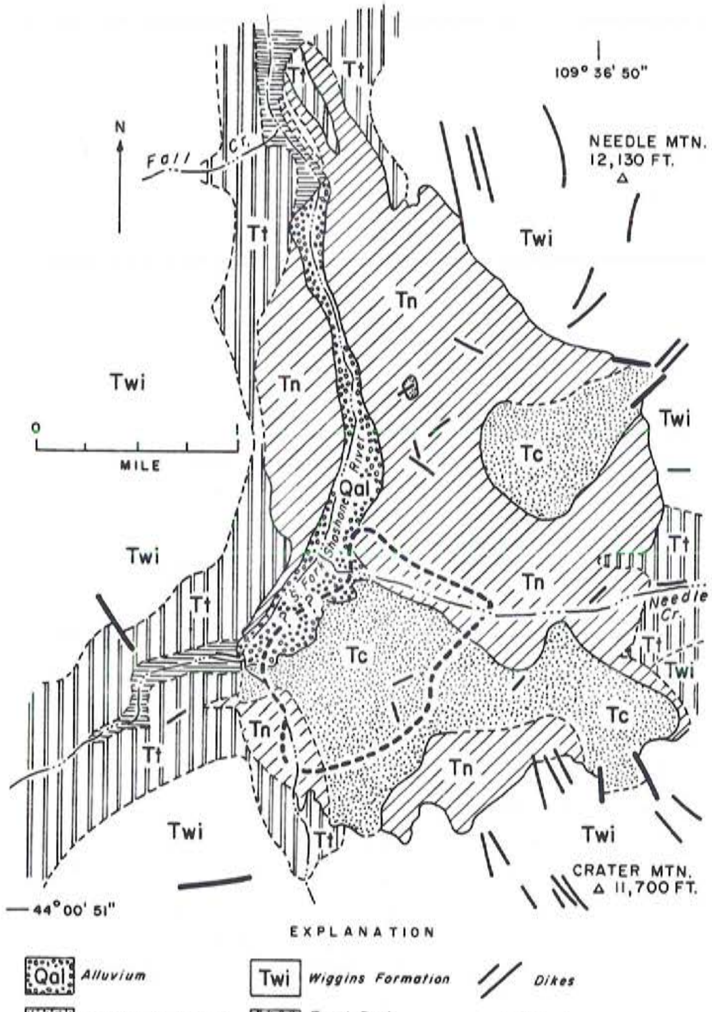

Figure 5: Generalized geological map of the Stinkingwater porphyry copper deposit (after Fisher, 1972).

dolomite, and minor siderite gangue. The veins are commonly crustiform and banded and are considered simple fracture fillings.

A supergene enriched chalcocite blanket, as much as 200 feet thick, was intersected by drill holes near the center of alteration at Crater Mountain. The extent of the supergene zone is not known. This zone is overlain by a leached and oxidized cap (Fisher, 1972).

Although an ore body of 65 million tons of 0.35 percent copper has been delineated by drilling, mineralization in the potassic core has not yet been entirely outlined by drilling (Geological Survey of Wyoming files, 1982).

Hydrothermal alteration increases in intensity towards the center of disseminated mineralization. Propylitization of both the intrusive and layered rocks is common throughout the district. The intensity of the propylitization increases around the fringe area of disseminated sulfide minerals. Propylitization gives way to phyllic alteration towards the center of alteration. The phyllic zone produces highly altered, bleached and silicified rock. In places, the original porphyritic texture is preserved by sericitic pseudomorphs; however, the original texture is completely destroyed in places of pervasive phyllic alteration. Potassic alteration (characterized by development of secondary biotite) is expressed in irregular ill-defined zones in the disseminated mineralized area.

Within the areas of supergene enrichment, there is evidence of argillic alteration which probably is of supergene origin.

Streams in the vicinity of the Stinkingwater mineralized area carry traces of gold (½-1 ppm in pan concentrates) and mercury (Fisher, 1972).

Silver Creek

Copper and minor molybdenite have been identified in altered rocks of an intrusive complex in the Silver Creek area. The complex is formed by dacite and rhyodacite rocks which intrude volcanics of the Wapiti Formation, Trout Peak Trachyandesite, and Wiggins Formation (Figure 6). The intrusive, as well as adjacent volcanics, shows effects of hydrothermal alteration (Fisher and others, 1977).

The Silver Creek area is located within the Washakie Wilderness on the Fall Creek 7½-minute quadrangle, and is accessible from the road's end at Valley along 11 miles of the South Fork pack trail to the mouth of Silver Creek. The intrusive is accessible within one-quarter mile from the mouth of Silver Creek, and lies within the Silver Creek stream valley (approximately 1½ miles southwest of the Stinkingwater mining region).

Hydrothermal alteration has affected the stock and adjacent host volcanics and generally preceded minerali-

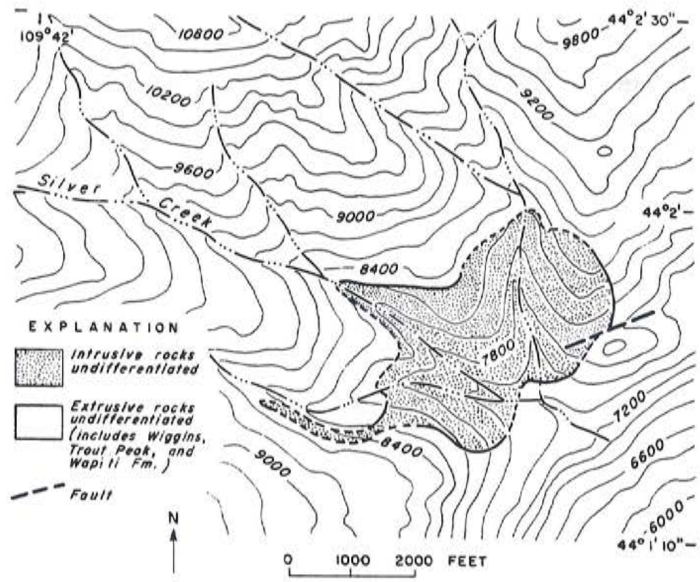

Figure 6: Generalized geological map of the Silver Creek mineralized stock (after Fisher and others, 1977).

zation. Widespread propylitic alteration laterally gives way to localized phyllic and potassic alteration near the center of the intrusive. Phyllic alteration is expressed by sericite, quartz and pyrite, which grade inward into small zones of alteration characterized by small quartz-potassium feldspar-veinlets and secondary biotite and magnetite. Alteration boundaries are indistinct and overlap. The major sulfides are localized within the phyllic and potassic alteration zones.

A well-developed pyrite halo is localized in the phyllic zone and encloses a highly mineralized 2,000 by 1,000 feet stockwork complex near the center of the intrusive. The highly mineralized zone contains disseminated malachite, chalcopyrite, bornite, and minor molybdenum, along with chalcopyrite-pyrite-magnetite quartz veinlets. Fractures in the stockwork area trend roughly N35° to N80°W, and dip steeply. These commonly are stained by malachite (Fisher and others, 1977).

Molybdenum is poorly expressed in rock outcrops although drilling has intersected strong molybdenum mineralization in 300 feet of core. Estimates of resources in the Silver Creek porphyry suggest that an ore body of at least 27 million tons of 0.5 percent copper is enclosed by the intrusive complex (Geological Survey of Wyoming files, 1982).

Birthday Area

The Birthday mineralized stock was discovered during a U.S. Geological Survey mineral evaluation survey of the Washakie Wilderness. The Birthday area is located on the

Needle Mountain and Emerald Lake 7½-minute quadrangles along the eastern flank of Crater Mountain. Access is by the South Fork Shoshone River pack trail to Saddle Creek. The intrusive lies at the headwaters of Saddle Creek.

Cody, Wyoming, is located about 45 miles northeast, Valley lies about 12½ miles north, and the Stinkingwater mining region is three miles north-northwest of the Birthday area.

Exposures of the intrusive crop out at three localities and cover an area of less than one-half square mile (Figure 7). The largest intrusive is granodioritic to dacitic in composition, and intrudes Wiggins Formation andesites and breccias.

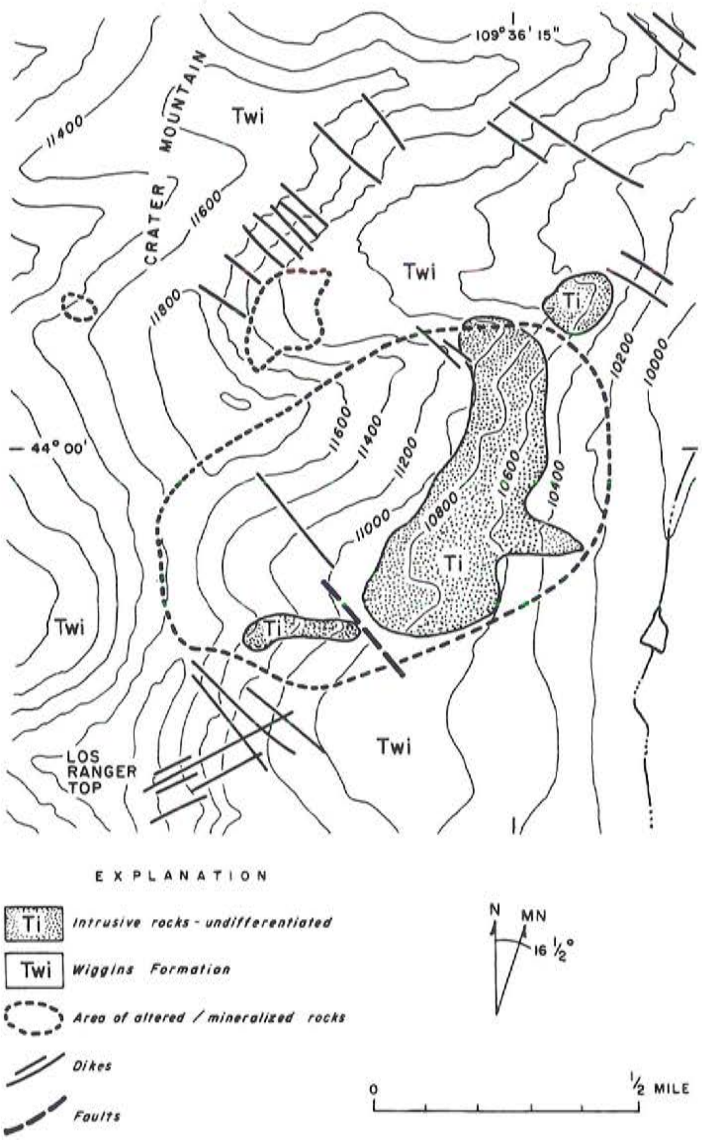

Figure 7: Generalized geological map of the Birthday mineralized intrusive complex (after Fisher and Antweiler, 1980).

Pyrite and chalcopyrite are widespread. Pyrite is disseminated, coats fractures, and occurs in quartz-pyrite veinlets. In some areas, pyrite comprises as much as 10 percent of the mineralized rock. Chalcopyrite occurs as disseminations and in veinlets forming stockworks. These stockworks are northwest-trending zones from 10 to 14 feet wide, that are developed in andesite dikes(?) and, to a lesser extent, in the dacite. Quartz-pyrite-calcite veins and altered rock occur adjacent to many of the dikes in the Birthday region. Oxidation is prominent, and zones of limonite, malachite, and azurite have replaced hypogene minerals. Both anomalous copper and molybdenum have been detected in assays.

Propylitic, phyllic, and potassic hydrothermal altered zones have been recognized in the Birthday area. The propylitic altered rocks are characterized by the development of chlorite, calcite, epidote, saussurite and pyrite. Phyllic altered rocks are present in scattered patches, and are mainly found in fractured zones, adjacent to dikes and veins, and along faults. Variable amounts of sericite, pyrite, and secondary quartz are present in the matrix, or replace phenocrysts, or are found in veinlets in the phyllic altered rocks. Potassic altered rock is present in two localized areas and is expressed by veinlet clusters containing actinolite/tremolite, potassium feldspar, magnetite, quartz, and chalcopyrite. Potassic altered zones are associated with high copper concentrations and mineralized stockworks (Fisher and Antweiler, 1980).

Robinson Creek

The Robinson Creek mineralized area was discovered by the U.S. Geological Survey during mineral evaluation studies of the Washakie Wilderness. The mineralized area lies nearly 50 miles southwest of Cody and 15 miles southwest of Valley. Access to the intrusive complex is by pack trail along the South Fork Shoshone River to Robinson Creek.

The mineralized area lies at the headwaters of Robinson Creek and includes a roughly one-square mile, hydrothermally altered and mineralized rhyodacite to dacite composite stock emplaced in flows and flow breccias of the Wiggins Formation (Figure 8). Texturally, the intrusive has both porphyritic and phaneritic phases.

Wiggins Formation andesites adjacent to the Robinson Creek intrusive are propylitized. Selectively pervasive propylitic alteration resulted in chlorite and lesser epidote replacing hornblende. Where propylitization is more intense, calcite, epidote, and minor chlorite are widespread. Secondary quartz, sericite, and pyrite form phyllic altered zones near the intrusive center. Some clay minerals replace phyllic zone minerals, and are apparently of supergene genesis. Other manifestations of supergene alteration are bleached and limonite-stained rocks.

Mineralization is coextensive with the phyllic altered zone, and is exposed as discontinuous outcrops of chalcopyrite, pyrite, and malachite stockworks. Chalcopyrite also occurs as disseminated grains and is found as fracture coatings with malachite. The mineralized rocks are extensively shattered with fracture zones trending from N20°W to N60°W, with less developed trends to the northeast. Anomalous lead, zinc, silver, and molybdenum have been detected by assay in the mineralized area (Fisher and Antweiler, 1980).

Clouds Home Peak

A complex pluton ranging from porphyritic dacite and rhyodacite to equigranular granodiorite and quartz monzonite intrudes Wiggins Formation flows and breccias in the Clouds Home Peak area. The mineralized pluton was discovered during a mineral evaluation of the Washakie Wilderness by the U.S. Geological Survey (Fisher and Antweiler, 1980).

The area of interest lies within the boundaries of the

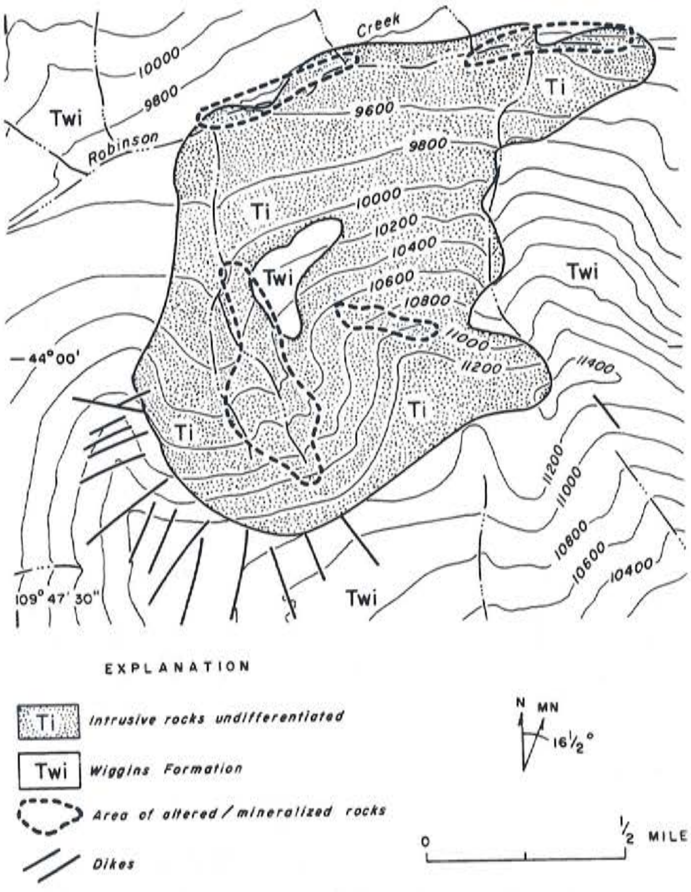

Figure 8: Generalized geologic map of the Robinson Creek mineralized stock (after Fisher and Antweiler, 1980).

Lake Creek and Clouds Home Peak 7½-minute quadrangles. The area is accessible by pack trail. The trail head intersects a paved and graded road that services Cody and Valley. Cody is located 25 miles to the northeast of the trail head, and Valley is eight miles to the south. From the Ishawooa Creek trail head, the base of Clouds Home Peak lies nearly 10 miles to the west. The intrusive complex is located near the top of the peak.

The intrusive complex crops out over an area of more than one-square mile (Figure 9). Mineralization and

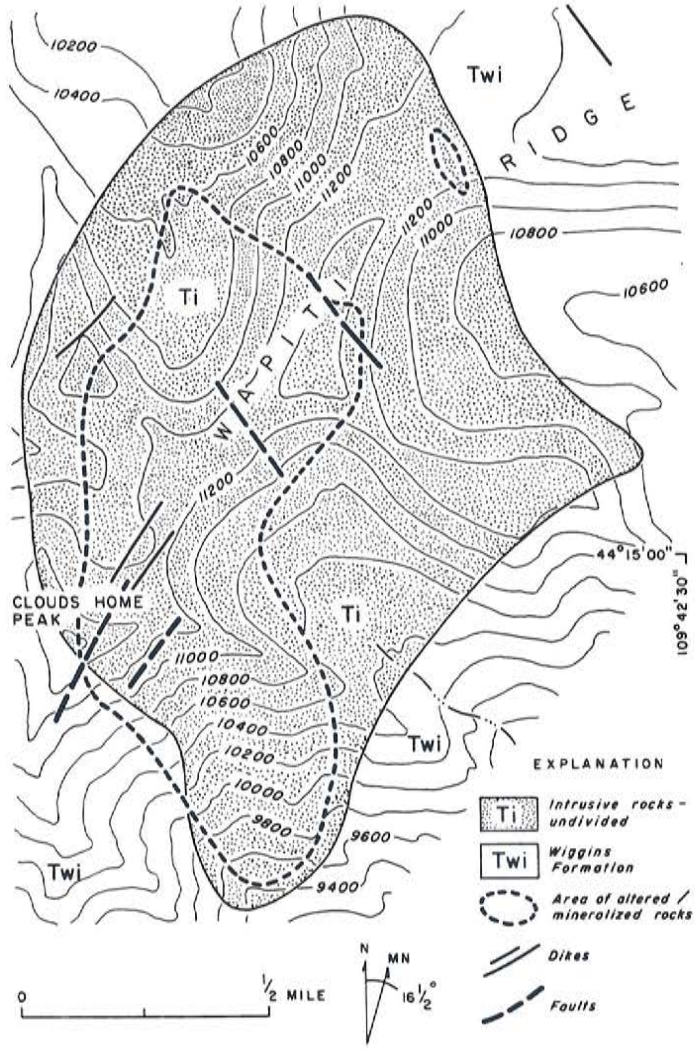

Figure 9: Generalized diagram of alteration and geology of the Clouds Home Peak intrusive complex (after Fisher and Antweiler, 1980).

alteration occur sporadically along a one-mile north-south trend located within the composite intrusive. According to Fisher and Antweiler (1980), about five percent pyrite and traces of chalcopyrite occur as disseminations and as fracture coatings in the intrusive, and also in some dikes. Other expressions of mineralization include: small pyrite, chalcopyrite, rhodochrosite, quartz veins (two inches and less, in width) that cut granodiorite rocks in a one-yard-wide zone; and a 30-feet-wide stockwork hosting malachite, azurite, chalcopyrite, quartz, pyrite, chlorite, and epidote. Anomalous copper, molybdenum, lead, and zinc are detectable in assays.

Alteration includes both propylitic and phyllic assemblages. The phyllic altered rock is restricted and closely associated with veins, shears, fractures, and dikes. Propylitic alteration is widespread. Oxidation has produced limonite staining, minor malachite staining, and bleaching of the rocks (Fisher and Antweiler, 1980).

Eagle Creek Mineralized Area

The Eagle Creek area lies near the edge of the Washakie Wilderness near the Yellowstone Park boundary, and about 40 air miles west of Cody, Wyoming. The district is accessible by 12 miles of pack trail (Eagle Creek trail) into the wilderness, and lies within T.51N., R.109W. on the Eagle Peak 15-minute quadrangle.

The region was prospected in 1911; and by 1955, 640 feet of drifts and 50 feet of shaft were developed on what is called the Crouch prospect, located near the south edge of the intrusive complex (Figure 10) (Osterwald and others, 1966; Wilson, 1956). The only recorded production was two ore shipments delivered to the Denver Mint in the 1930's that were valued at $1,000 in gold (Wilson, 1956).

The country rock, in the Eagle Creek region, is formed of andesite flows and flow breccias of the Trout Peak Trachyandesite (Sunlight Group). These two formations, in the immediate area of interest, are vent-series facies and are mapped as undifferentiated andesites.

Mineralization is directly related to the emplacement of an irregularly-shaped intrusive (post-Oligocene?) averaging latite (monzonite) composition. This latite porphyritic intrusive has been selectively fractured and mineralized, and exhibits stockwork mineralization near the east-central edge of the intrusive, where the intrusive lies within a topographic saddle (Figure 10). The stockwork is expressed by narrow N32°E and N64°W trending quartz veinlets carrying pyrite, chalcopyrite, and galena. A further expression of mineralization extends out from the stockwork and into silicified and altered latite porphyry and also into relatively fresh latite porphyry (Tlp) on the northwestern edge of the saddle. This mineralization occurs as pyrite disseminations and as narrow pyrite, galena, sphalerite, chalcopyrite quartz veins (less than one inch wide) in the altered-silicified latite, and as fine pyrite and chalcopyrite(?) disseminations in the gray latite porphyry (Tlp). There is no evidence that supergene enrichment is important in the district (Galey, 1971). Some placer gold is

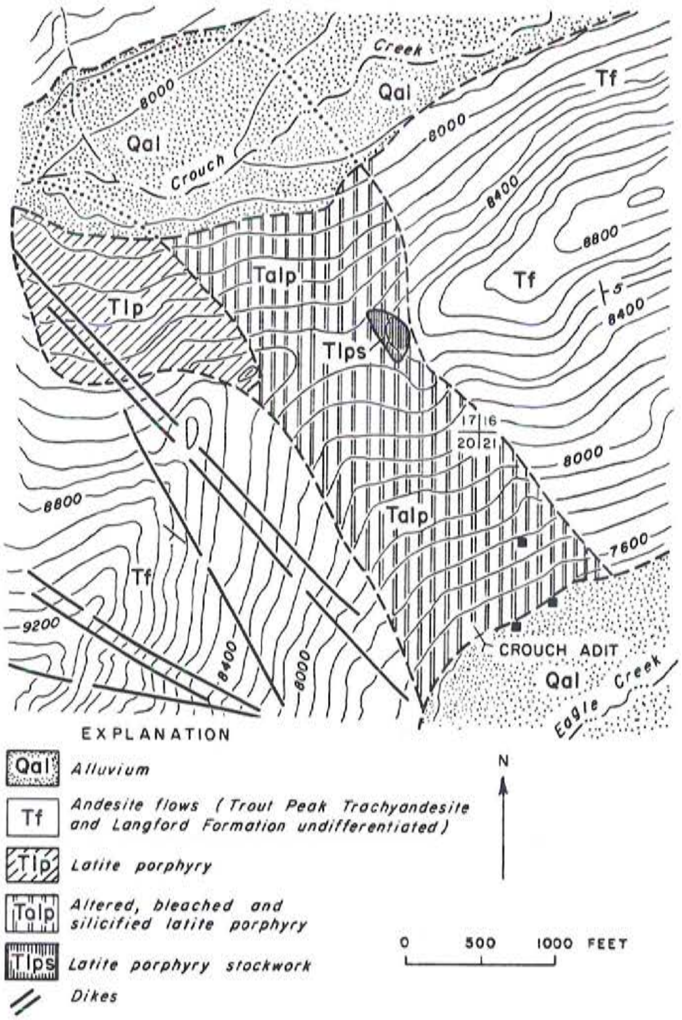

Figure 10: Generalized geological map of the Eagle Creek mineralized area (T.51N., R.109W.). Base metal deposits of the Eagle Creek region are associated with intrusive latite porphyry. There is little evidence for supergene enrichment (after Galey, 1971).

reported along Eagle Creek and along Crouch Creek (Wilson, 1956).

Hydrothermal alteration is intense near the central portion of the stockworks, and is characterized by phyllic and potassic alteration assemblages. The intense alteration, laterally gives way to regional prophylitic alteration (Galey, 1971).

Sunlight Mineralized Area

The Sunlight mineralized area is located on U.S. Geological Survey 15-minute topographic quadrangles Dead Indian Peak (1956) and Sunlight Peak (1956). The nearest population center is Cody, Wyoming, located 40 miles east of the mineralized area, although the Sunlight Basin area houses numerous private cabins and summer homes. Osterwald and others (1966), Parsons (1937), Williams (1980a), Elliott (1980a) and Hausel (1980) provide overviews of the Sunlight deposits. Rich (1974), Pedersen (1968), and Drier (1967) conducted thesis investigations in the area.

The first report of prospecting in the Sunlight area occurred in 1890 and the only report of ore production was 100 tons of gold, silver, and copper ore mined in 1903 (Williams, 1980a, p. 34). Several hundred feet of exploratory workings have been developed by shaft and adits at several mine sites. All of these historic workings were developed along vein mineralization.

Two types of mineralization are recognized in the district; these are disseminated deposits and vein mineralization. The disseminated deposits consist of (1) pyrite in altered zones in all rock types, (2) chalcopyrite in intrusive rocks, and (3) copper-bearing stockworks (Elliott, 1980a). Fairly well-developed stockworks are developed in syenite stock at the headwaters of Sulfur Creek (Drier, 1967), and in andesites in contact with syenite (Wilson, personal comm., 1982). The stockworks consist of less than one inch wide veins and veinlets hosting chalcopyrite, bornite, covellite and chalcocite in quartz, calcite gangue (Figure 11).

Vein mineralization is zoned, and forms copper-rich veins near the mineralized centers, and lead-silver or barren veins at a distance from the stocks.

Three alteration zones are recognized in the district — propylitic, argillic, and potassic. Propylitic alteration is widespread and increases in intensity near the intrusive stocks and veins. While potassic alteration is localized and restricted to the stocks, argillic alteration appears to be supergene in origin and overprints the other two alteration phases.

Primary controls on the mineralization were the intrusive masses and associated fracture systems. Disseminated mineralization is localized in and around intrusives, and veins are controlled by joint sets and shear zones (Elliott, 1980a) (Figure 11).

New World - Cooke City

The New World district (often referred to as the Cooke City district) is located along the Montana-Wyoming border adjacent to Cooke City, Montana. Cooke City is nearly 50 air miles northwest of Cody, and lies on the eastern edge of the Absarokas. Most of the district is within the State of Montana, although 22 mining claims, and a portion of the underground workings of the Irma-Republic mines, penetrate into the North Absaroka Wilderness of Wyoming (Williams, 1980b).

The ore deposits in the New World district are related to a deeply dissected intrusive-volcanic complex. Due to uplift, this complex has been more deeply eroded than any of the other known mineralized centers in the Absarokas. Precambrian gneiss, Paleozoic sediments, and Tertiary intrusives (diorite to syenite) are exposed throughout most of the district. On the western and southern edges, andesitic flows are still preserved and unconformably rest on Paleozoic sediments (Elliott, 1980b).

The Goose Lake and Henderson Mountain stocks, located north of Cooke City, are recognized centers of mineralization. With a few exceptions, the major ore bodies are localized adjacent to the stocks.

The Goose Lake center, located north of the Henderson stock, exhibits mineralization somewhat different from the Henderson lodes. The host rocks for the Goose Lake stock are mafic and felsic igneous rocks. The veins are localized and form principally chalcopyrite, and galena-sphalerite vein deposits adjacent to the intrusive.

The Henderson Mountain mineralization primarily occurs as fissure-replacement deposits. The ore shoots and lodes are best developed at fracture intersections and in sheeted zones. Alteration associated with the mineralization is expressed as silification and dolomitization (Lovering, 1929).

The mineralization extends out from Henderson Mountain in irregular metallogenic zones. Contact-metamorphic gold-copper deposits are developed adjacent to the stock and these grade outward to copper-lead ore. The copper-lead mineralization is further zoned to copper-lead-zinc, and, at greater distances from the stock, to complex lead-silver-zinc, then to an aureole of silver-bearing sideritic calcite veins and finally to barren carbonate veins at greater distances. The better deposits are developed where these zoned veins cut limestone beds of the Pilgrim Limestone (Gallatin Formation) of upper Cambrian age to form replacement lodes, although the underlying Gros Ventre Limestone (middle Cambrian) is an untested potential host (Lovering, 1929; Reed, 1950; Butler, 1965).

Irma-Republic Mines. The Irma-Republic deposits are a vein system of the Henderson Mountain complex. These deposits are formed by fracture fillings and replacements enclosed by oolitic beds of the Pilgrim Limestone. The system is near vertical and strikes N30° to 40°W. Mine workings in the Irma-Republic lode are over 2,700 feet in length and extend to a depth of 250 feet. Silver, lead, and zinc have been extracted from the deposits. Reported production from these mines is more than 18,000 tons of gold, silver, copper, lead, and zinc concentrates (Williams, 1980b).

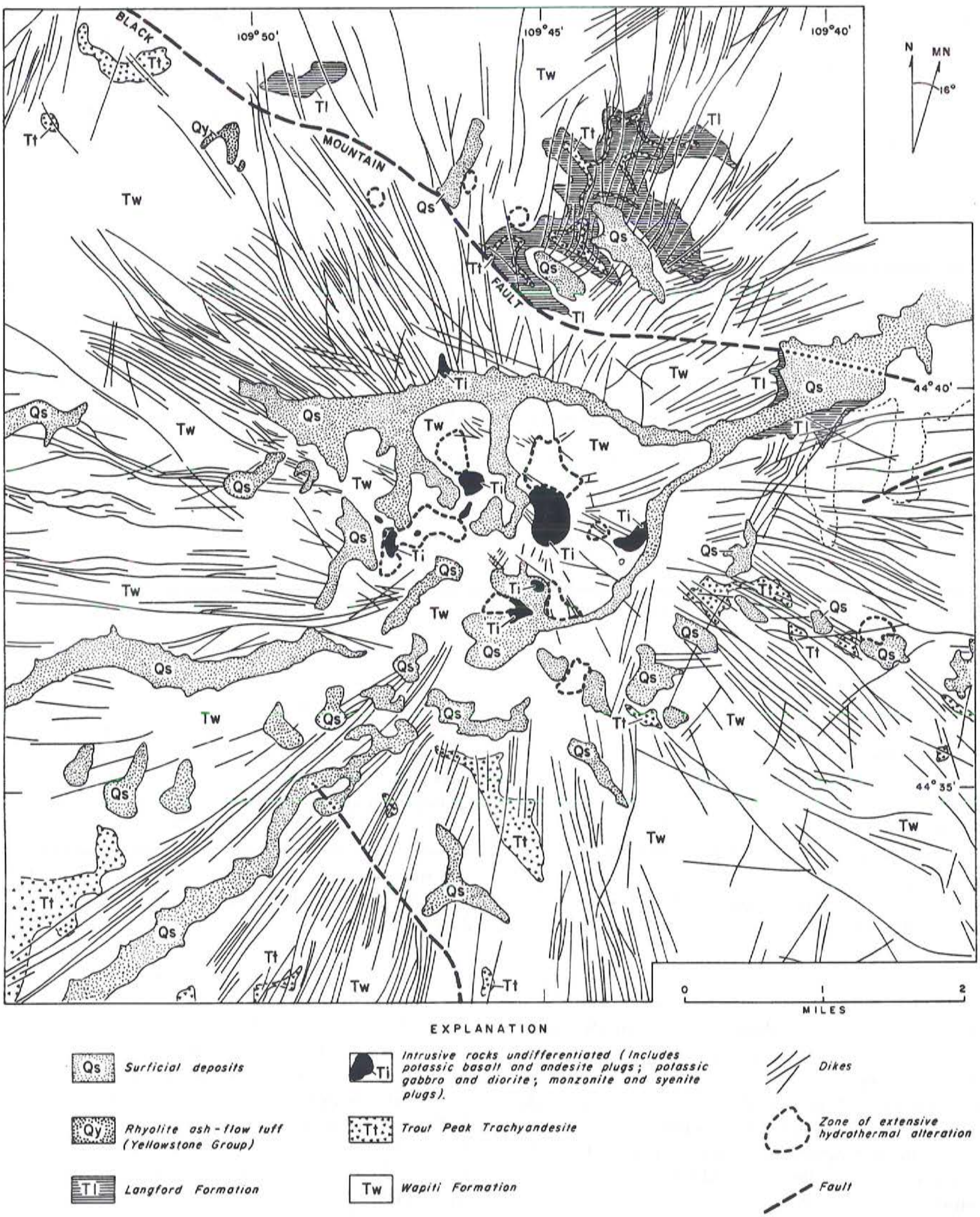

Figure 11: Geological map of the Sunlight intrusive center (after Nelson and others, 1980).

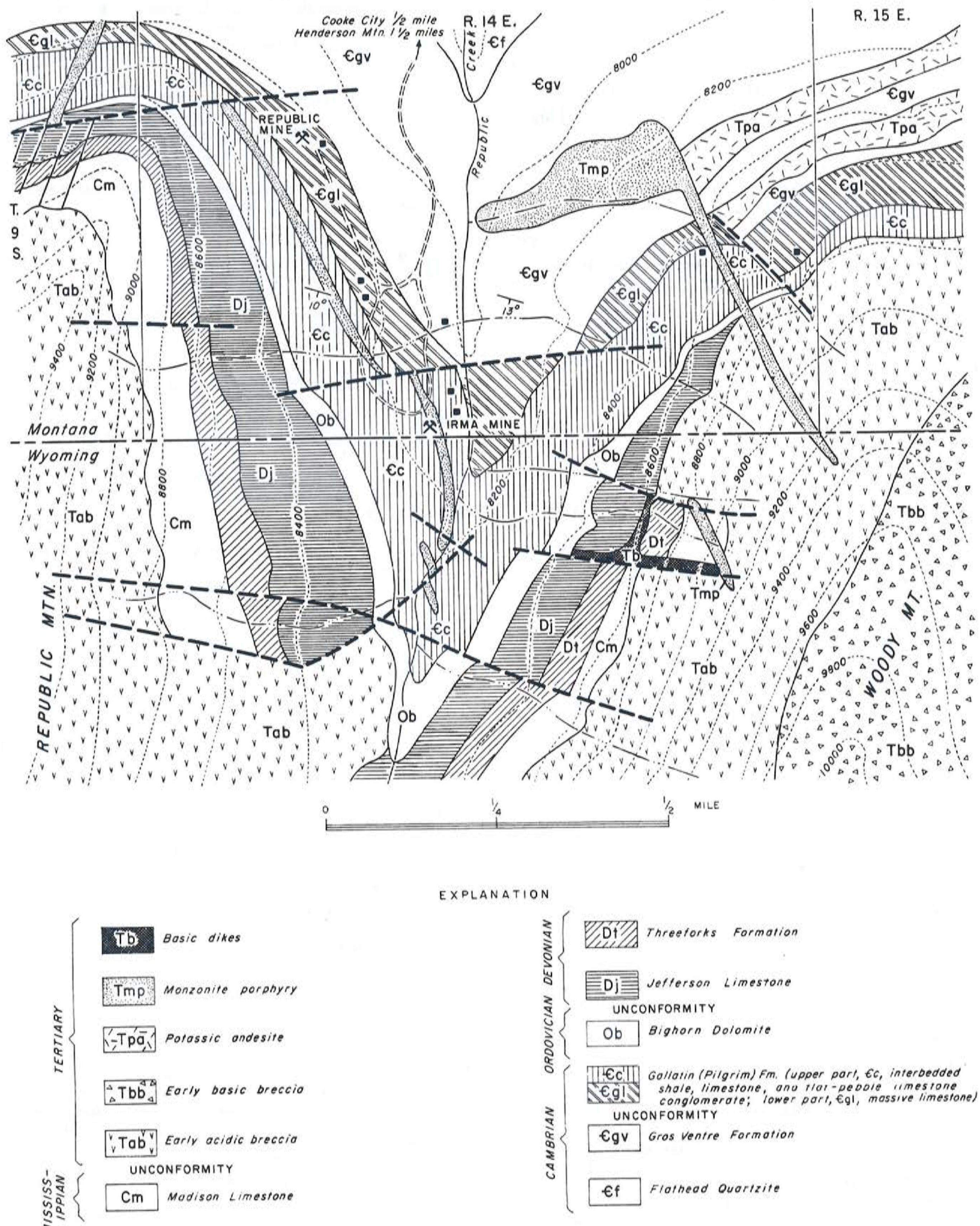

Figure 12: General Geological map of the southern New World district (after Lovering, 1929).

SUMMARY

The Absaroka volcanic plateau contains a well-defined trend of porphyry copper-molybdenum deposits. This trend forms a north-northwesterly lineament marked by mineralized composite intrusives possibly controlled by a deep-seated fracture.

These mineralized centers represent a large potential resource of copper, molybdenum, and other associated base metals and precious metals, but the inclusion of these deposits within and immediately adjacent to wilderness boundaries will greatly restrict mining and production.

There is potential for discovery of additional mineralized porphyry systems, and the search for these should concentrate on felsic composite intrusive complexes in areas of vent facies volcanics (andesite flows and flow breccias).

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