UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Preliminary manuscript for
"Mineral-Resource Potential and Geology of the
Challis $1^{o}x2^{o}$ Quadrangle, Idaho"

Edited by

Frederick S. Fisher[1] and Kathleen M. Johnson[2]

Open-File Report 87-480

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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Reston, Virginia

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MINERAL-RESOURCE POTENTIAL AND GEOLOGY OF THE CHALLIS $1^{o}x2^{o}$ QUADRANGLE, IDAHO

Edited by Frederick S. Fisher and Kathleen M. Johnson

ABSTRACT

By Frederick S. Fisher and Kathleen M. Johnson

The Challis, Idaho $1^{o}x2^{o}$ quadrangle has seen modest but continuous production of mineral commodities since gold was discovered in the 1860s. Recorded production includes more than 900,000 oz gold, 26,000,000 oz silver, 10,000,000 lb copper, 150,000,000 lb lead, and 60,000,000 lb zinc. The Bayhorse district produced silver and base metals every year from the early 1900s to 1986. During World War II, more than 800,000 short ton units of WO_3 and 14,000 tons of antimony were extracted from the Yellow Pine district. In the period 1955-59, the Bear Valley placer deposit yielded 1,050,000 pounds combined niobium and tantalum. At present (1985) mining activity centers around production of molybdenum and precious metals, while exploration is focused on precious metals. Historically, price has been the most important control on mining and exploration. Recently land use regulations have had an increased influence and at present large areas of the quadrangle are covered by special mining and development regulations.

Eight geologic terranes, each recognized by characteristic age, lithology, structure, and geochemical and geophysical signatures, are found in the Challis quadrangle. Each terrane also includes a characteristic suite of mineral commodities and mineral deposit types. The Precambrian rock terrane is located in the northcentral and northeastern parts of the quadrangle and includes quartzites, argillites, and siltites and their metamorphic equivalents, all of Proterozoic age. The carbonate rock terrane, in the southeastern quarter of the quadrangle, incorporates Proterozoic to Mississippian limestones and dolomites. The black shale terrane is part of a belt of metalliferous, black, siliceous-facies, clastic sedimentary rocks, of Late Cambrian to Permian age, that trends south from the central part of the Challis quadrangle into the central part of the Hailey quadrangle. Both the carbonate rock terrane and the black shale terrane are cut by large thrust faults, along which the rocks were transported from the west. The western half of the Challis quadrangle is underlain chiefly by the Idaho batholith terrane, including the six types of Cretaceous granitic rocks that make up the Atlanta lobe of the batholith. The northern and eastern parts of the quadrangle are covered by the calc-alkaline extrusive and hypabyssal rocks of the Challis volcanic rock terrane; dacitic to rhyodacitic flows, rhyolitic caldera-forming eruptive sequences, and volcaniclastic sediments crop out across the area. The Eocene plutonic rock terrane comprises small to large intrusions of pink hornblende-bearing granite and grey diorite; the intrusions are found scattered across the central part of the quadrangle. These six terranes are all crosscut by north- and northwest-trending high angle faults. The alluvial deposits terrane comprises unconsolidated or poorly consolidated fluvial deposits of Quaternary age. The trans-Challis fault system terrane is a structural terrane made up of northeast-trending high angle faults and volcanotectonic structures; it crosses the quadrangle from the southwest corner to the northeast corner.

More than 1,000 mines and prospects have been located within the Challis quadrangle. Thirty-four different types of deposits have been recognized; they contain 21 commodities, including antimony, barium, beryllium, cobalt, copper, fluorspar, gold, lead, manganese, mercury, molybdenum, niobium, rare earth elements, silver, tantalum, thorium, tin, tungsten, uranium, vanadium, zeolites and zinc. Geologic features of the quadrangle suggest the possibility of occurrence of seven additional deposit types, which would contain alunite, copper, gold, mercury, silver, and uranium.

Mineral resources of the Challis quadrangle were assessed using a simple subjective assessment method that depends heavily on the experience and expertise of the assessors. These assessments show significant resources in several deposit types. Resources of national importance include: the largest known deposits of black sands in the United States, containing rare earth elements, monazite, and thorium; large deposits of molybdenum; disseminated deposits of vanadium, base, and precious metals; small deposits of acid grade fluorspar; and tungsten and antimony in deposits like that at Yellow Pine. Resources of importance on a regional scale include base metals in the Bayhorse district, precious metals in several deposit types throughout the quadrangle, and tungsten skarns in the central part of the quadrangle.

INTRODUCTION

By Frederick S. Fisher

This report and U.S. Geological Survey maps I-1819, MF-???, MF-???, Open Files OF-???? and OF-???? constitute the Challis mineral resource folio which represents the end product of a five-year study conducted under the Conterminous United States Mineral Assessment Program (CUSMAP) of the U.S. Geological Survey. Geological, geochemical, and geophysical field and laboratory studies were integrated into an analysis of the mineral potential of the Challis $1^{o}x2^{o}$ quadrangle (hereafter in this report the use of the term Challis quadrangle, unless otherwise noted, refers to the $1^{o}x2^{o}$ quadrangle and not the 15-minute quadrangle of the same name). The Challis quadrangle was selected for study because it includes a large amount of federally owned land that contains a wide variety of ore deposits within extensive mineralized areas. Many of these ore deposits are associated with specific geologic terranes that extend beyond the quadrangle boundaries; thus the assessment methods, diagnostic criteria, and geological parameters of many of the ore deposit types may be used to evaluate the mineral potential of a much larger contiguous area of central Idaho.

Many maps and reports generated by the Challis CUSMAP study have been published previously and are listed at the end of this report. U.S. Geological Survey Bulletin 1658, "Symposium on the geology and mineral deposits of the Challis $1^{o}x2^{o}$ quadrangle, Idaho," (McIntyre, 1985) was a progress report for the Challis CUSMAP project as of 1983. Some of the data presented in Bulletin 1658 have been superseded by information in this report, particularly the descriptions of ore deposits and resource assessments.

This report considers all mineral and rock commodities known or suspected to occur within the geological environments of the Challis quadrangle. It excludes oil, natural gas, and coal. Land status and classification, mining laws and development restrictions, and socio-political viewpoints were not used in assigning resource potentials to any given tract of land. Nor were any economic factors or mining feasibility studies taken into account in the resource appraisals. It should be pointed out, however, that large areas of the quadrangle are covered by special mining and development regulations, which would have to be considered in planning mineral resource development.

Final editing of this report was done by Frederick S. Fisher and Kathleen M. Johnson. Authorship of the numerous individual sections is indicated at the beginning of each chapter. Many individuals, not reflected in the authorship, have contributed to the data base used in this report, including John E. Callahan, E. Bartlett Ekren, James A. Erdman, Richard F. Hardyman, Stephen S. Howe, Reed S. Lewis, David H. McIntyre, Peter J. Modreski, and George J. Neuerburg. Acknowledgment and a hearty thanks are given to the many individual residents of the Challis quadrangle who provided access to private lands, hospitality, aid, and mining information to the U.S. Geological Survey field geologists and crews. We also express our appreciation to the miners and mining companies working in the region for sharing their knowledge and expertise. The superb cooperation of the U.S. Forest Service greatly increased the efficiency of the field operations of the project. In particular we would like to acknowledge the help of Bill Savage, Minerals Technician for the Challis National Forest, who coordinated the efforts between the two agencies and helped solve innumerable logistical difficulties.

The Challis quadrangle (pl. 1) is in central Idaho north of the Snake River Plain. The largest community in the quadrangle is Challis, with a population of 794. Other settlements are Stanley, Lowman, Garden Valley, Clayton, Obsidian, and Yellow Pine, all with populations of less than 100.

More than 95 percent of the quadrangle is federally owned land, encompassing parts of the Boise, Challis, Payette, Salmon, and Sawtooth National Forests. Large tracts of land in the southeastern one-fourth of the quadrangle are administered by the Bureau of Land Management. Nearly one-third of the area is within either the Frank Church-River Of No Return Wilderness or the Sawtooth National Recreation Area (pl. 1).

Most of the quadrangle is mountainous. Elevations range from a low of 3,000 ft in the valley of the South Fork of the Payette River, where it exits the quadrangle in the southwest, to a high of 11,815 ft at the summit of Castle Peak in the White Cloud Peaks (pl. 1). Local relief of 3,000-4,000 ft is common throughout the area, and canyons and valleys are steep sided. Much of the terrane is moderately to heavily forested and generally below timberline; however, parts of the White Cloud Peaks, the Sawtooth Range, and other scattered mountains rise well above timberline and have subalpine climates.

Wherever it is necessary to use place names in the text either the location in question appears on one of the maps or geographic coordinates to the nearest minute have been provided. An index map to 7 1/2- and 15-minute quadrangles included within the Challis quadrangle is shown on plate 1.

Principal industries in the area are farming, ranching, lumbering, mining, and recreation.

GEOLOGIC SETTING AND MINERALIZATION HISTORY

By Frederick S. Fisher

Five main groups of rocks are present in the Challis quadrangle (fig. 1). Precambrian sedimentary and metamorphic rocks crop out in the northern and eastern parts of the area. Paleozoic sedimentary rocks are mostly in the south-central and eastern areas with scattered outcrops through the central part of the quadrangle. The Cretaceous Idaho batholith occupies the western half and the Tertiary Challis volcanic field covers most of the eastern half of the area. Tertiary batholiths and stocks are well developed in the central part of the quadrangle.

Four major structural features characterize the Challis quadrangle (fig. 1). These are: the trans-Challis fault system which is expressed by northeast-trending high-angle faults, fracture systems, dike swarms, and grabens; a north- and northwest-trending system of high-angle faults; caldera and collapse features associated with the Challis volcanic field; and extensive thrust faults in the Paleozoic rocks.

The earliest metallogenic event was concentration of base and precious metals in the Precambrian. Nearly 1 billion years of sedimentary history are represented by argillic rocks of the Middle Proterozoic Yellowjacket Formation and quartzite and siltite of the Lemhi Group, the Hoodoo Quartzite, and the Swauger and Lawson Creek Formations. Mafic tuffs and dikes dated at about 1.7 b.y. are present within the Yellowjacket sequence (Hughes, 1982). Later Precambrian igneous activity consisted of intrusion of granitoid plutons about 1.5-1.3 b.y. ago (Evans and Zartman, 1981). Hughes (1982) suggests that the argillaceous rocks of the Yellowjacket Formation were deposited in a rift

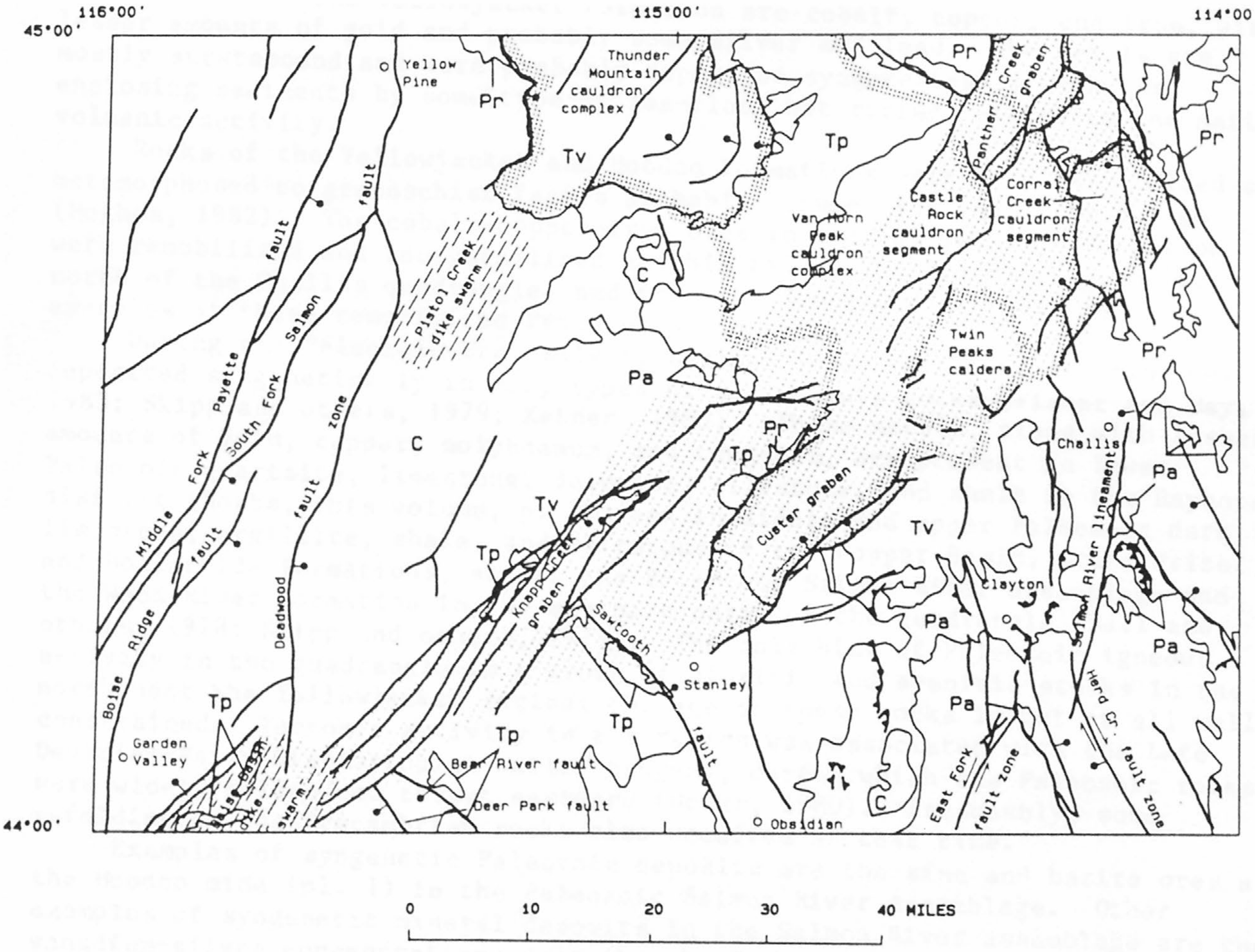

Figure 1. MAP SHOWING PRINCIPAL GEOLOGIC FEATURES OF CHALLIS 1°X2° QUADRANGLE

EXPLANATION

CONTACT		Tv	TERTIARY VOLCANIC ROCKS
FAULT--Bar and ball on downthrown side; arrows show relative displacement		Tp	TERTIARY PLUTONIC ROCKS
THRUST FAULT--Sawteeth on upper plate		C	CRETACEOUS INTRUSIVE ROCKS
CALDERA BOUNDARY		Pa	PALEOZOIC SEDIMENTARY ROCKS
DIKE SWARM		Pr	PRECAMBRIAN SEDIMENTARY AND METAMORPHIC ROCKS
TRANS-CHALLIS FAULT SYSTEM			

basin bordering the craton and that they represent depositional environments ranging from basinal to deepwater clastic fan deposits and turbidites. Metals concentrated in the Yellowjacket Formation are cobalt, copper, and iron, with lesser amounts of gold and probably some silver and lead. The metals are mostly stratabound and were probably deposited syngenetically with the enclosing sediments by some type of sea-floor hot spring related to the mafic volcanic activity.

Rocks of the Yellowjacket and Hoodoo Formations were complexly folded and metamorphosed to greenschist facies probably between 1.4 and 1.2 b.y. ago (Hughes, 1982). The cobalt-copper-iron ores in the Yellowjacket Formation were remobilized and recrystallized at this time. The Blackbird deposit, north of the Challis quadrangle, and the Iron Creek deposit (pl. 1) are examples of these remobilized Precambrian deposits.

During the Paleozoic Era, silver, barium, lead, vanadium, and zinc were deposited syngenetically in many types of sedimentary rocks (Fisher and May, 1983; Skipp and others, 1979; Ketner, 1983). These metals, along with lesser amounts of gold, copper, molybdenum, and tungsten, are present in lower Paleozoic quartzite, limestone, dolomite, siltstone, and shale in the Bayhorse district (Hobbs, this volume, p. 20) and in middle and upper Paleozoic dark limestone, argillite, shale, and siltstone of the Copper Basin, Grand Prize, and Dollarhide Formations, and in the Paleozoic Salmon River assemblage and the Wood River Formation in the southern parts of the quadrangle (Hall and others, 1978; Skipp and others, 1979). The only hint of Paleozoic igneous activity in the quadrangle is a group of dioritic and syenitic stocks in the north near the Yellowjacket region; the age of these rocks is not at all well constrained. Tectonic activity in the region was associated with the Late Devonian-Early Mississippian Antler orogeny, during which the Paleozoic rocks were widely folded and thrust eastward (Dover, 1980). Presumably, some refolding of the Precambrian rocks also occurred at that time.

Examples of syngenetic Paleozoic deposits are the zinc and barite ores at the Hoodoo mine (pl. 1) in the Paleozoic Salmon River assemblage. Other examples of syngenetic mineral deposits in the Salmon River assemblage are the vanadium-silver concentrations described by Fisher and May (1983) and possibly the lead-silver ores at the Livingston mine (pl. 1). The Lower Permian fine-grained carbonaceous basinal sedimentary rocks have potential for deposits of zinc, lead, and barite in the Grand Prize and Dollarhide Formations (Hall and Hobbs, this volume, p. 29; Skipp and others, 1979). All of these syngenetic ores show varying degrees of remobilization during Late Cretaceous and Tertiary igneous activity.

The intrusion of several phases of the Idaho batholith and satellite stocks from about 112 to 70 m.y. ago dominated the Cretaceous Period. Folding and eastward thrusting of Paleozoic rocks were widespread before and during batholith intrusion and culminated during the Sevier orogeny in Late Cretaceous time (Skipp and Hall, 1975). Some normal faulting also occurred during this time, and contact metamorphism was intense locally (Anderson, 1948).

Intrusion of various phases of the batholith probably remobilized yet again the Precambrian cobalt-copper-iron deposits; certainly the Paleozoic syngenetic silver, barium, lead, and zinc deposits were remobilized to differing degrees. Skarn deposits containing silver, gold, barium, copper, molybdenum, lead, tungsten, and zinc were formed at this time in roof pendants and adjacent to the batholith, as were the Thompson Creek and Little Boulder Creek porphyry molybdenum deposits (pl. 1). The most widely accepted age for the Thompson Creek deposit is 88 m.y. (Marvin and others, 1973). Vein and replacement lead-silver deposits in the Bayhorse district, specifically the Skylark vein (pl. 1), have been dated at 95 m.y. (McIntyre and others, 1976; recalculated).

The source of the metals in the skarns, the porphyry molybdenum, and the vein-replacement deposits is a matter of conjecture. It is probable that the metals in these deposits were derived from metalliferous Paleozoic and Precambrian rocks by hydrothermal systems associated with the various intrusive phases of the batholith; the batholith itself contributed little metallic content to the ore deposits of the region. The batholith did, however, contribute euxenite and columbite in pegmatites, and monazite as a primary disseminated mineral. These minerals contain valuable concentrations of niobium, tantalum, thorium, uranium, and the rare-earth elements, and accumulated in placer deposits as a result of late Tertiary weathering followed by stream-winnowing concentration during the Pleistocene and Holocene (Schmidt and Mackin, 1970).

Tertiary time was characterized by the deposition of the Eocene Challis Volcanic Group, the development of the Challis volcanic field, and the emplacement of several batholiths and many stocks (fig. 1). Prior to the igneous activity, however, the Idaho batholith was being eroded, and arkosic sediments were deposited locally. These sediments eventually were the traps for stratabound uranium deposits in the Stanley region (Choate, 1962). Volcanism began with the widespread eruption of lavas of intermediate composition about 51 m.y. ago (McIntyre and others, 1982). Lavas were intermittently erupted for another 5 to 6 m.y. About 48 m.y. ago the character of volcanic activity changed and ash-flow eruptions predominated. These eruptions led to the development of the cauldron complexes, starting with the Van Horn Peak cauldron complex, which was closely followed by and probably partly concurrent with the formation of the Custer graben, and the Thunder Mountain and Twin Peaks calderas (Fisher and Johnson, this volume, p. 51). The size and shape of the calderas were closely related to pre-existing graben-bounding northeast-trending faults. Northeast- and northwest-trending high-angle faults began to form at least 51 m.y. ago, as dated by lavas that ponded against pre-existing fault scarps (McIntyre and others, 1982).

Intrusive activity from 50 to about 43 m.y. ago resulted in the emplacement of the Casto pluton, the Sawtooth batholith, and many other smaller stocks and countless dikes (Bennett, 1980). From 43 to 39 m.y. ago, extensive shallow rhyolitic intrusions and dikes were emplaced (Fisher and Johnson, this volume, p. 51). Limited age data suggest that at least some of the intrusive activity in the Boise Basin dike swarm occurred as recently as 29 m.y. ago (Kiilsgaard and Bennett, this volume, p. 54).

A great diversity of deposits is associated with Tertiary igneous activity (pl. 1). The oldest date we have so far in the Tertiary is 45 m.y. for the Golden Sunbeam gold-silver deposit (Johnson and McIntyre, 1983). The General Custer epithermal gold-silver vein deposit is dated at 43 m.y., the Red Mountain gold-molybdenum deposit in high-level rhyolite at 39 m.y., and the Little Falls vein-fracture molybdenum deposit at 29 m.y. (pl. 1) (Johnson and McIntyre, 1983). To the best of our knowledge, then, most of these metals were deposited in a minimum time span of 16 million years. A broad paragenetic sequence of three stages can be postulated for Tertiary mineral deposits in the Challis quadrangle: a base-precious metal stage, overlapped and followed by a fluorite and possibly mercury episode, in turn overlapped and followed by zeolite development. This sequence is strictly conjecture at present, as we do not have detailed dating of the different stages. However, the major fluorspar and zeolite deposits and possibly also the mercury deposits all are spatially separate from the main areas of base- and precious-metal deposits.

Hundreds of deposits within the quadrangle exemplify Tertiary mineralization. A few examples are: the lead-silver-antimony-tin veins in the Wood River Formation in the southern part of the quadrangle; tungsten-antimony-gold deposits at Yellow Pine; stratabound and vein uranium deposits near Stanley; vein fluorspar deposits near Meyers Cove, Challis, and Stanley; mercury vein-replacement deposits in roof pendants near Yellow Pine; and most of the epithermal gold-silver vein deposits in the quadrangle.

The source of the metals for the extensive Tertiary mineralization is still an enigma. Did the Tertiary plutons, much as the Idaho batholith, simply provide a driving mechanism for convecting hydrothermal systems, or were the plutons themselves metalliferous? Geochemical evidence suggests that the Tertiary granites were enriched in beryllium, uranium, thorium, molybdenum, and tin (Bennett, 1980). However, as suggested by Howe and Hall (1985), the sulfur isotopes indicate a crustal source for the sulfur.

GEOLOGIC TERRANES

INTRODUCTION

By Frederick S. Fisher

Eight geologic terranes have been identified in the Challis quadrangle. These are the Precambrian, carbonate rock, black shale, Idaho batholith, Challis volcanic rock, Tertiary plutonic rock, alluvial deposits, and trans-Challis fault system terranes (pl. 2). Seven of the terranes contain suites of rocks or sediments related by age, origin, and petrographic character. The eighth terrane (the trans-Challis fault system) includes a group of structures including faults, grabens, calderas, aligned plutons, and dike swarms. Each of the terranes contains some distinctive ore deposits and also some ore deposits that are present in other terranes. Each terrane has had a somewhat different history of mineralization, but commonly metals introduced in one terrane were remobilized and form important ore deposits in other terranes. For example, metals deposited syngenetically in the black shale terrane have been remobilized by igneous activity associated with the emplacement of the Idaho batholith and also Tertiary plutons and have been redeposited as epigenetic ores in other terranes. Another example is gold-bearing veins in the trans-Challis fault system terrane that have been eroded to form gold placers in the alluvial deposits terrane.

The geologic characteristics of each terrane provide the basis for describing the recognition criteria for the known ore deposit types and also for defining the parameters of hypothetical ore deposits within the quadrangle.

The terrane map (pl. 2) is simplified from the geologic map of the Challis quadrangle (Fisher and others, in press), for detailed information the reader is referred to that publication. Table 1 lists the types of known ore deposits in each terrane. The reader is cautioned to remember that the occurrence of a deposit type in a particular terrane does not necessarily imply a genetic or age relation with the rocks of that terrane.

Table 1.--Ore deposit types and host geologic terranes in the Challis quadrangle

	Terranes							
	Precambrian rock terrane	Carbonate rock terrane	Black shale terrane	Idaho batholith terrane	Challis volcanic rock terrane	Eocene plutonic rock terrane	Alluvial deposits terrane	Trans-Challis fault system terrane
KNOWN ORE DEPOSIT TYPES								
Veins								
Precious metal	◒	--	--	◒	●	●	--	●
Mixed base and precious metals	○	◒	◒	●	--	--	--	○
Lead-silver-zinc-antimony-tin	--	--	--	--	--	--	--	--
Fluorspar	--	◒	--	●	●	●	--	●
Uranium	--	--	--	◒	--	○	--	--
Tungsten	○	--	--	●	--	--	--	--
Manganese replacement	--	--	--	--	--	○	--	--
Semiprecious opal	--	--	--	--	○	--	--	--
Stockworks								
Cretaceous molybdenum stockworks	--	--	●	●	--	--	--	--
Tertiary molybdenum stockworks	--	--	--	--	--	●	--	--
High-level rhyolite-hosted precious metal	--	--	--	--	●	--	--	●
Disseminations								
Graphite in metamorphic rocks	○	--	--	○	--	--	--	--
Pegmatites								
Mica, feldspar, columbite, and rare-mineral	--	--	--	●	--	--	--	--
Piezoelectric quartz crystal-bearing	--	--	--	●	--	--	--	--
Miarolitic cavities								
Semiprecious gemstone	--	--	--	--	--	●	--	--
Skarns								
Polymetallic	●	--	●	●	--	--	--	--
Irregular replacements								
Rare earth	○	--	--	○	--	--	--	--
Base and precious metal	--	●	--	--	--	--	--	--
Mercury	◒	--	--	--	--	--	--	--
Zeolites in tuffaceous rocks	--	--	--	--	◒	--	--	--
Stratiform replacements								
Precious metals in epiclastic sediments	--	--	--	--	●	--	--	--
Precious metals in volcanic tuffs	--	--	--	--	●	--	--	--
Fluorspar in carbonate rocks	--	●	--	--	--	--	--	--
Barite	--	--	◒	--	--	--	--	--
Uranium in sedimentary rocks	--	--	--	--	○	--	--	--
Stratabound syngenetic								
Vanadium	--	--	◒	--	--	--	--	--
Precious and base metals in argillic rocks and micritic limestone	--	--	●	--	--	--	--	--
Cobalt-copper deposits	●	--	--	--	--	--	--	--
Placers								
Gold	--	--	--	--	--	--	●	--
Radioactive black-sand	--	--	--	--	--	--	●	--
Rock products								
Quartzite (flagstone)	--	●	--	--	--	--	--	--
Granite (building stone)	--	--	--	●	--	--	--	--
Volcanic tuff (building stone)	--	--	--	--	●	--	--	--
Sand and gravel	--	--	--	--	--	--	●	--
POSTULATED ORE DEPOSIT TYPES								
Opalite-type mercury veins	--	--	--	--	X	--	--	--
Uranium in sedimentary rocks in contact zones with granitic rocks	X	X	X	X	--	X	--	--
Hot-springs gold deposits	--	--	--	--	X	--	--	X
Vein and replacement alunite deposits	--	--	--	--	X	X	--	X
Silver deposits in caldera-filling lake sediments	--	--	--	--	X	--	--	X
Carlin type carbonate-replacement gold deposits	--	X	X	--	--	--	--	--
Stratabound copper-silver deposits in Precambrian quartzites	X	--	--	--	--	--	--	--

● Ore deposit type is well developed in this terrane; examples of deposit type are identified and recognition criteria are reasonably well understood.

◒ Ore deposit is less well developed in the indicated terrane but is not uncommon.

○ Ore deposit type is present in the indicated terrane but is either well understood and poorly developed or too poorly developed to be well understood.

-- Ore deposit type is not known to be present in the indicated terrane.

X Terrane(s) in which the postulated ore deposit type may be present.

NOTE: The symbols do not indicate the number of mines or prospects present but rather a combination of the extent of our knowledge about the ore deposit type and the degree of its geologic development in any given terrane. This is perhaps best expressed diagrammatically as:

<--increasing knowledge

increasing geologic development --->			
	●	◒	○
	◒	◒	○
	○	○	○

Table 2 shows the geochemistry of the known ore deposit types that are listed on table 1. Of the 30 elements listed in table 2, 20 are present in one or more of the different deposit types as ore or possible byproducts. Silver, gold, copper, lead, and zinc are common ore metals in many of the deposits and together account for most of the value of the past production from the quadrangle. Arsenic occurs in a wide range of deposit types and is a useful pathfinder element for base- and precious-metal veins, high level rhyolites, polymetallic skarns, and most of the replacement and stratabound syngenetic deposits. Antimony is also quite common and may be used as a pathfinder for most of the vein deposits and several of the irregular and stratiform replacement deposits.

PRECAMBRIAN ROCK TERRANE

By S. Warren Hobbs and Theresa M. Cookro

Precambrian stratified rocks and their metamorphic equivalents within the Challis quadrangle are probably all of Proterozoic age. These rocks are best exposed in the northeastern and northwestern quadrants of the quadrangle (fig. 1; pl. 2). Roof pendants in the Idaho batholith have been mapped in the central part of the quadrangle and several clusters of small pendants are in the northwest corner.

PROTEROZOIC ROCKS

Seven units make up the known Proterozoic section within the quadrangle. From oldest to youngest, these are the Yellowjacket Formation, the Hoodoo Quartzite, and the Big Creek, Apple Creek, Gunsight, Swauger, and Lawson Creek Formations. Of these, the Big Creek and Gunsight have very limited exposures. The following discussion will summarize the essential features of each of the units but must rely heavily on exposures beyond the quadrangle borders for those units with abbreviated sections within the map area.

YELLOWJACKET FORMATION

The Yellowjacket Formation was named by Ross (1934b, p. 16) from exposures in the Yellowjacket mining district which is along the northeastern border of the Challis quadrangle. Ross (1934b) described the formation as dark-gray, more or less argillaceous fine-grained quartzite containing some intervals as much as 100 ft thick of white quartzite and thicker intervals of dark-gray, fine-grained quartzite. The lower part of the section includes metamorphosed lenses, as much as 1,700 ft thick, of calcareous strata that are banded and variegated; colors include gray, white, and green. At the type locality, the section is incomplete and estimated to total somewhat less than 9,000 ft in thickness. At no place in the numerous localities in east-central Idaho where the Yellowjacket Formation has been studied is a depositional base exposed. Extensive exposures of rocks to the east and west of the type Yellowjacket, separated from it by intrusive rocks of Cretaceous and Tertiary age or by thick cover of Eocene Challis Volcanic Group, have been identified as part of the Yellowjacket sequence although they include notable differences in composition, sequence, thickness, and degree of metamorphism. Because of these differences, and the wide separation in location, they will be described separately.

Table 2.--Geochemistry of known ore deposit types

[● = ore, o = possible byproduct, . = geochemically anomalous]

	Ag	As	Au	Ba	Be	Bi	Cd	Co	Cr	Cu	F	Hg	Mn	Mo	Nb	Ni	Pb	REE	Sb	Se	Sn	Ta	Te	Th	Ti	U	V	W	Zn	Zr
Veins																														
Precious metal	●	.	●			.				o	.	.					o		.										o	
Mixed base and precious metals	o		o	.						●	.						●		.										●	
Lead-silver-zinc-antimony-tin	●	.	o			.	.			●							●		o		o		.						●	
Fluorspar	.		o	.							●			.					.		.									
Uranium	o	.	o							.	.			.			.		.							●			.	
Tungsten	o	.	o														.		●									●	.	
Manganese replacement													o																	
Semiprecious opal																														
Stockworks																														
Cretaceous molybdenum stockworks	●		.							o				●			o											o	.	
Tertiary molybdenum stockworks	.									●				●																
High-level rhyolite-hosted precious metal	●	.	●		.						.			.						.										.
Disseminations																														
Graphite in metamorphic rocks																														
Pegmatites																														
Mica, feldspar, columbite, and rare mineral					o								.		o			.				o								
Piezoelectric quartz crystal-bearing																														
Miarolitic cavities																														
Semiprecious gemstone					o						.																			
Skarns																														
Polymetallic	●	.	o			.				●				.			●											●	●	
Irregular replacements																														
Rare earth		.		.								.	.					o												.
Base and precious metals	●	.	.							●	.						●		.										●	
Mercury		.										●							.											
Zeolites in tuffaceous rocks																														
Stratiform replacements																														
Precious metals in epiclastic sediments	●	.	●																.											
Precious metals in volcanic tuffs	●	.	●							.				.					.									.	.	
Fluorspar in carbonate rocks		.		.						.	●						.												.	
Barite				●										.															.	
Uranium in sedimentary rocks		.																	.							●				
Stratabound syngenetic																														
Vanadium	o	.		o					.					.		.	o			.							●		o	
Precious and base metals in argillic rocks and micritic limestone	o	.		.													●												●	
Cobalt-copper deposits		.				.		●		●						.														
Placers																														
Gold	●		●									.			o			o	.			o		o		o				
Radioactive black-sand	o		o												●			o				●		●		●				

The Yellowjacket exposures in the vicinity of Iron Creek (44°55′ N., 114°05′ W.) and Panther Creek, in the northeast part of the quadrangle, are part of an extensive area of Yellowjacket Formation studied by D. A. Lopez (1981). Lopez describes the section as predominantly medium-gray to dark-gray argillaceous quartzite and sandy or silty argillite. The rocks are in the lower greenschist facies of regional metamorphism and primary sedimentary features are easily identifiable. Much of the section is well laminated with graded bedding in both laminae and beds and has many aspects of a turbidite sequence. The total thickness of the Yellowjacket in the Blackbird-Panther Creek area is estimated to be between 20,000 and 26,000 ft. Complex structure and discontinuous exposures of the Yellowjacket make accurate measurement impossible in the Challis quadrangle.

Five members have been identified by Lopez (1981) in the Yellowjacket. Three of these are well exposed in the Challis quadrangle; the other two are best exposed just north of the quadrangle. Figure 2 is a generalized composite stratigraphic column that has been modified from Lopez (1981) and gives the localities where each member has been identified. The general characteristics of the five members in sequence from base to top as adapted from Lopez (1981) are as follows:

Member A.--Graded beds 4 to 36 in. thick of coarse- to medium-grained quartzite that grades upward into very fine or fine-grained argillaceous quartzite and locally sandy argillite. Upsection this member becomes finer grained overall and darker in color. The member is about 2,300 ft thick.

Member B.--Predominantly very fine grained argillaceous quartzite and siltite. Graded beds are 2 to 20 in. thick. Characteristic of this member are beds and lenses of calcareous quartzite. It is about 5,300 ft thick.

Member C.--Characterized by couplets of light-colored argillaceous quartzite and (or) siltite and dark-colored sandy argillite that occur together in graded laminae and beds from 0.1 to 6 in. thick. The member is about 4,300 ft thick.

Member D.--Predominantly very fine grained argillaceous quartzite in graded beds 4 to 36 in. thick. The member is at least 8,200 ft thick but may be as much as 11,500 ft.

Member E.--Comprises quartzites with the lowest content of argillaceous matrix of all the formation. Graded beds are from 1 to 6 ft thick. The exposed thickness of Member E is about 330 ft.

At the Blackbird district, 20 mi northwest of the Panther Creek-Iron Creek area and in the Elk City 1°x2° quadrangle, strata mapped as Yellowjacket are divided into three major units that total 17,000 ft in thickness (Hahn and Hughes, 1984). The middle unit contains significant amounts of volcanic and subvolcanic material, and also hosts the ore deposit at the Blackbird cobalt deposit that is thought to be related to the volcanism. No volcanic component has been reported in the section described by Lopez (1981) in the Challis quadrangle, although several occurrences of Blackbird-type mineralization occur in the Yellowjacket on Iron Creek.

Extensive exposures of sedimentary and volcanic rocks of heterogeneous composition occur about 40 mi west from the Yellowjacket mining district in and near the Yellow Pine and Big Creek areas, straddling the boundary between the Challis and Elk City quadrangles. A significant part of the sequence has

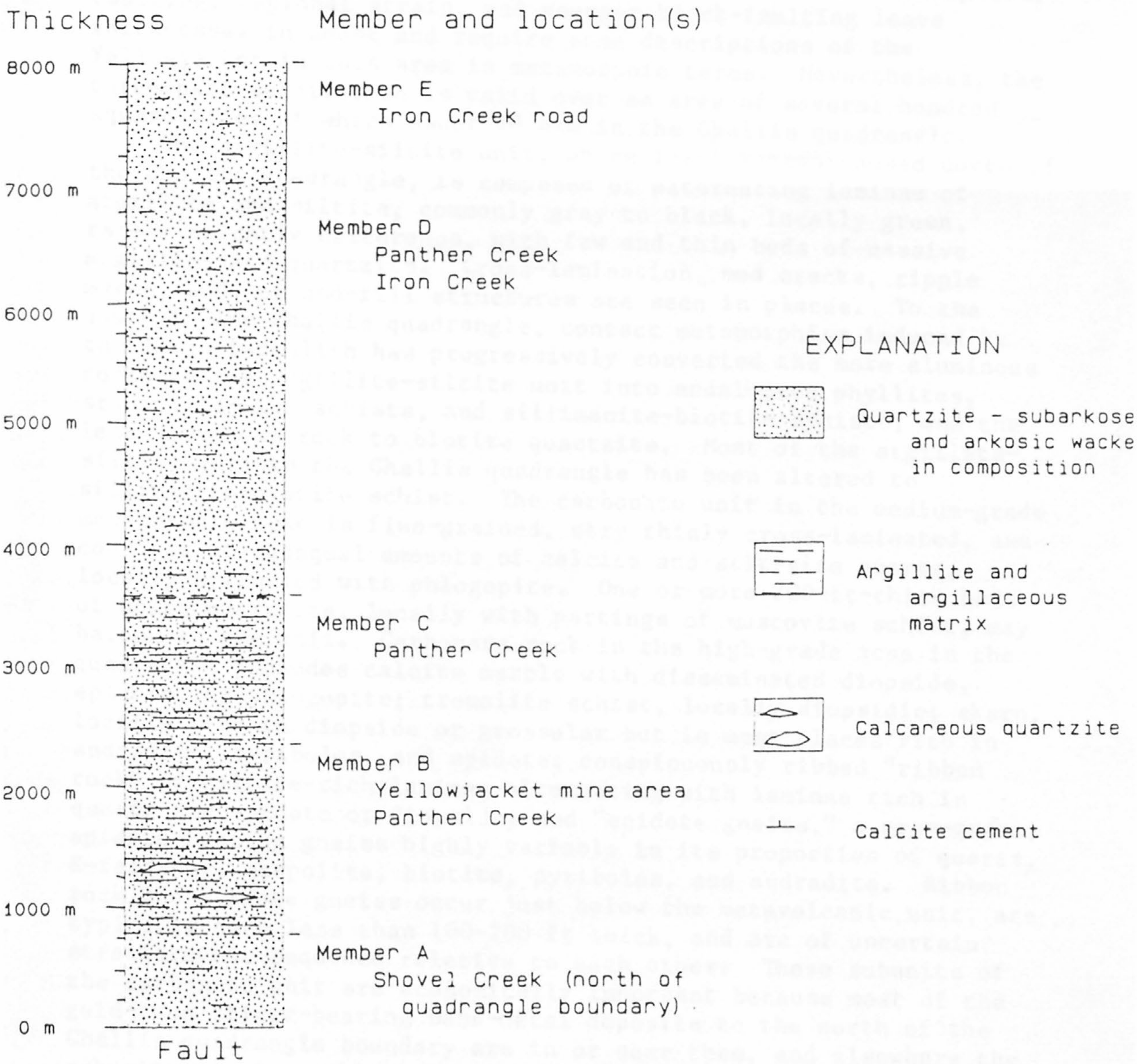

Figure 2. Composite stratigraphic column of the Yellowjacket Formation, showing areas where each member was studied

been assigned to the Yellowjacket by B.F. Leonard, on the basis of extensive detailed work in these general areas. Leonard's description says:

> The Yellowjacket Formation in the Yellow Pine area is broadly divisible into three parts. In ascending order these are: (1) argillite-siltite unit, several thousand feet thick, base not exposed; (2) carbonate unit, thickness perhaps 500-2,500 ft; and (3) metavolcanic unit, thickness perhaps 500-2,000 ft. Pre-batholith deformation, syn-batholith deformation and metamorphism, faulting, regional strain, and younger block-faulting leave thicknesses in doubt and require some descriptions of the Yellowjacket in this area in metamorphic terms. Nevertheless, the three-part subdivision is valid over an area of several hundred square miles of which about 40 are in the Challis quadrangle.
>
> The argillite-siltite unit, where least metamorphosed north of the Challis quadrangle, is composed of alternating laminae of argillite and siltite, commonly gray to black, locally green, rarely slightly calcareous, with few and thin beds of massive argillite and quartzite. Cross-lamination, mud cracks, ripple marks, and cut-and-fill structures are seen in places. To the south in the Challis quadrangle, contact metamorphism induced by the Idaho batholith has progressively converted the more aluminous rocks of the argillite-siltite unit into andalusite phyllites, staurolite-mica schists, and sillimanite-biotite schists, and the less aluminous rock to biotite quartzite. Most of the argillite-siltite unit in the Challis quadrangle has been altered to sillimanite-biotite schist. The carbonate unit in the medium-grade metamorphic zone is fine-grained, very thinly cross-laminated, and consists of subequal amounts of calcite and silt-size quartz, locally sprinkled with phlogopite. One or more 200-ft-thick beds of white quartzite, locally with partings of muscovite schist, may belong in the unit. Carbonate rock in the high-grade zone in the quadrangle includes calcite marble with disseminated diopside, epidote, or phlogopite; tremolite schist, locally diopsidic; skarn, locally rich in diopside or grossular but in most places rich in andradite, pyriboles, and epidote; conspicuously ribbed "ribbon rock" of calcite-rich laminae alternating with laminae rich in quartz and epidote or diopside; and "epidote gneiss," a gray-green, epidote-bearing gneiss highly variable in its proportion of quartz, K-feldspar, scapolite, biotite, pyriboles, and andradite. Ribbon rock and epidote gneiss occur just below the metavolcanic unit, are typically each less than 100-200 ft thick, and are of uncertain stratigraphic sequence relative to each other. These subunits of the carbonate unit are economically important because most of the gold- and silver-bearing base-metal deposits to the north of the Challis quadrangle boundary are in or near them, and elsewhere the subunits are favorable host rocks for gold deposits.
>
> The metavolcanic unit (Leonard, 1962) is not exposed in the low-grade zone. Epidote amphibolite and a trace of metamorphosed welded rhyolite tuff are present in the medium-grade zone. Amphibolite and felsic biotite hornfels are common in the high-grade zone; remnants of welded tuff and volcanic breccia are rare. In places, the hornfels contains a little hornblende and epidote. (B.F. Leonard, written commun., 1985)

HOODOO QUARTZITE

The Hoodoo Quartzite was named by Ross (1934b, p. 18) from exposures along the west slopes of the valley of Hoodoo Creek (44°59′ N., 114°34′ W.) located about 2 1/2 mi west of the Yellowjacket mine (pl. 1). This unit is exposed in many places across the northernmost part of the Challis quadrangle, always in close association with the Yellowjacket Formation. It is also widespread in the same association in the southern part of the Elk City quadrangle to the north. The relationship of the Hoodoo to the Yellowjacket has long been a subject of controversy and alternative interpretation. In most places, the Hoodoo is in steep fault contact with the Yellowjacket, but at the type locality and a few other places depositional top and bottom contacts have been identified. Ross (1934b) noted that the Hoodoo was definitely younger than the Yellowjacket on which it appeared to rest with a gradational contact. B.F. Leonard (written commun., 1985) considered the Hoodoo Quartzite in the Yellow Pine and Big Creek area to be structurally, but not stratigraphically, conformable with the underlying Yellowjacket Formation. In a comprehensive study of the Hoodoo Quartzite and its relation to the Yellowjacket Formation, Ekren (in press) considers that both the basal and upper contacts of the Hoodoo are locally exposed and are transitional into the Yellowjacket below and into a series of unnamed beds above that are also of Yellowjacket affinity, and may be as much as 3,300 ft thick. At the type locality these unnamed beds have been mapped as part of the Yellowjacket Formation by Ekren, who considers the Hoodoo to be a facies of the Yellowjacket; however, Bennett (1977) mapped the same overlying sequence as a part of the Hoodoo Quartzite.

The Hoodoo Quartzite is dominated by massive, fine- to medium-grained very light colored quartzite that is mostly white or off-white with a tannish cast, but with light brownish color on joint surfaces that are stained with limonite. In a very few places the rocks are light yellowish-gray, dark-gray and even black where metamorphic biotite and amphibole have developed from argillaceous impurities that are more prevalent in the basal part of the unit. Most of the rock contains 85-90 percent quartz in grains that range in size from 0.2 to 1.5 mm but are mostly less than 1 mm. Feldspar, mostly microcline and orthoclase, but with different amounts of albite, ranges from 5 to 10 percent of the rock, and muscovite, sericite, and chlorite may range from 0 to 10 percent. Proportions of these components vary somewhat from top to bottom in the section and to a certain extent from place to place. Most of the bedding is indistinct, but crossbedding in beds 1-3 ft thick has been observed in places. Both oscillatory and current ripple marks are found throughout the section. Intense fracturing and breakdown of the well-jointed quartzite produces a scree of hackly fragments that obscures internal structures, bedding, and the contact with the underlying Yellowjacket Formation.

In its type area the Hoodoo, as measured by Ross (1934b, p. 16), is 3,560 ft thick and its basal contact is gradational. Because the upper contact in this locality is also considered to be gradational (Ekren, in press) this may well be a complete section. Other areas of outcrop are incomplete because of structural complexity.

BIG CREEK FORMATION

Strata that are tentatively assigned to the Big Creek Formation occur in three small areas in the northeast corner of the Challis quadrangle (Fisher and others, in press). These strata are a small sample of the formation that is one of the thickest and most widespread formations of the Lemhi Group in the central part of the Lemhi Range, southeast of the Challis quadrangle (Ruppel, 1975).

The Big Creek Formation comprises light-greenish-gray to light-gray, predominantly fine-grained micaceous quartzite that is moderately to strongly feldspathic and speckled with grains of iron oxide. In some places colors of the rock include pale olive, pale red, and orange pink. Weathering colors are generally light gray to light brownish gray. In the Lemhi Range section, bedding is predominantly medium to thick or massive. In the Challis quadrangle only about 600 ft of strata, with no top or base, are exposed. Bedding is mostly medium with considerable thin bedding present as well.

APPLE CREEK FORMATION

More than 50 sq mi of thin- to thick-bedded, greenish-gray to green to dark-gray siltite and argillite containing interbedded thin lenses of fine-grained, gray, argillaceous quartzite, assigned to the Apple Creek Formation, occur in the northeast corner of the Challis quadrangle (Fisher and others, in press). This unit was first named the Apple Creek Phyllite by Anderson (1961) and redefined as the Apple Creek Formation by Ruppel (1975) in its type area in the northern part of the Lemhi Range. Both Lopez (1981) and Ekren (in press) recognized these strata as allochthonous in the Challis quadrangle and thrust over the Yellowjacket from the east, probably on the Medicine Lodge thrust system (Ruppel, 1978). Their correlation with the type Apple Creek is based on the predominance of siltstone and argillite, lenses of fine sandstone, and the generally thin bedding and evidence of shallow water deposition. Ripple marks and mudcracks are locally abundant; many beds are laminated or cross-laminated and many bedding surfaces are coated by coarse detrital muscovite. In many places, the Apple Creek has a well-developed cleavage. No base or top is exposed in the quadrangle, and the thickness is unknown because of extensive folding and thrust faulting. As much as 2,000 ft may be present in the quadrangle.

One aspect of the Apple Creek Formation in the northern part of the Lemhi Range, east of the Challis quadrangle, and at Ellis, on the Salmon River near the eastern border of the quadrangle, is the presence of ferrodolomite as cement in the sandstone lenses of the formation. This aspect appears to be absent in most of the rocks called Apple Creek in the Challis quadrangle. Although many features of the Apple Creek Formation are similar to those of parts of the Yellowjacket, the basic evidence favors correlation with the type Apple Creek Formation.

GUNSIGHT FORMATION

Three small areas of strata that are tentatively assigned to the Gunsight Formation occur in the northeast corner of the quadrangle where they are bounded by steep faults and are in contact with Yellowjacket, Apple Creek, or Big Creek Formations, or the Challis Volcanic Group; in a few places Challis Volcanic Group overlaps the Gunsight. The unit covers less than 3 sq mi in the Challis quadrangle but is very widespread in the Lemhi Range to the east and southeast (Ruppel, 1975).

In the Challis quadrangle, the Gunsight is a light-brownish-gray, fine- to medium-grained, poorly sorted, thin- to medium-bedded sericitic quartzite; many beds are laminated and cross-laminated. Parts of the unit are tinted purplish gray and grayish red purple and contain abundant magnetite in rounded detrital grains that are scattered through the rock and concentrated in laminae and cross laminae. Much of the Gunsight is dirtier than the Big Creek Formation that it closely resembles. No known ore deposits are associated with the Gunsight in the Challis quadrangle.

SWAUGER FORMATION

The Swauger Formation in the Challis quadrangle crops out in three north-northwest-trending nearly parallel areas near the northeastern edge of the quadrangle. The three exposed areas are four to five miles apart and represent a thick section of the formation that has been repeated. The structural history is unknown.

The Swauger is widely exposed in the northern part of the Lemhi Range and farther south along its west flank where it was named and described by Ross (1947). More recent studies by Ruppel (1968, 1975, 1980) have refined the unit and its stratigraphic relations. Characteristics of the Swauger in the Challis quadrangle are virtually identical to those of the formation in the Lemhi Range. Most of the formation is a light-pink, pinkish-tan, or purplish-gray to locally red, fairly pure quartzite comprising well-rounded, medium to coarse, moderately well-sorted quartz grains. Locally the rock contains several percent feldspar and scattered grains of quartz. Fine-grained hematite provides the reddish coloration and local blotchy appearance. Beds are from 0.5 to 6 ft thick, but most commonly are 3-6 ft thick, and many beds are prominently and coarsely cross-laminated; some are ripple marked. In places the quartzite beds are separated by thin partings of dark-greenish-gray siltite or argillite.

The thickness of the Swauger in the Challis quadrangle is not certain because the base is not exposed. However, the top contact is well defined by the gradational zone of the overlying Lawson Creek Formation and each of the three duplicated sections comprises approximately 10,000 ft of section. These facts suggest that the total thickness may not be much in excess of the 10,000 ft estimated for the maximum exposed section in the Lemhi Range, where the base of the Swauger is gradational from the Gunsight Formation, although at that locality a thrust fault defines the top of the formation.

No ore deposits of any consequence are known to be associated with the Swauger Formation. Use of quartzite of this formation for building stone is limited by distance to market and high transportation costs.

LAWSON CREEK FORMATION

The Lawson Creek Formation is the uppermost known formation of the seven Proterozoic units in east-central Idaho. Although the type section is in the southwest part of the May 15-minute quadrangle, adjacent to and east of the Challis 15-minute quadrangle, other occurrences are found in the Challis 15-minute and Twin Peaks 15-minute quadrangles (pl. 1) within the east-central part of Challis quadrangle (Hobbs, 1980). The total exposed extent of the Lawson Creek Formation is less than 3 sq mi, and in all but one occurrence the formation is demonstrably conformable with and gradational from the underlying

Swauger Formation. A maximum measured thickness is approximately 4,300 ft, and at all exposures the formation is unconformably overlain by Eocene Challis Volcanic Group.

The Lawson Creek Formation is a sequence of medium-reddish-purple to dark-purplish-gray and maroon impure quartzite, siltstone, and argillite that is predominantly thin bedded but which locally contains thick beds of light-purple quartzite and zones of intermixed medium- to thick-bedded quartzite, siltstone, and thinly bedded silty argillite. The quartzite beds are generally less pure than those in the Swauger and are locally highly feldspathic; the entire section shows an abundance of mud chip breccia, ripple marks, and micaceous partings.

The formation can be divided into three informal units. These are: (1) a basal 820 ft thick transitional zone from the Swauger Formation; (2) a middle interbedded quartzite and silty argillite unit 1,486 ft thick, and (3) an upper thin-bedded and laminated argillite unit that is at least 1,900 ft thick. The transitional zone is predominantly quartzite that is similar in many ways to the Swauger but generally is thinner bedded, dark reddish purple, less pure, and less indurated. Thin interbeds of silty quartzite and siltstone are more abundant toward the top. Although the member is predominantly dark colored and generally thinner bedded, thick beds of pure, light-pink quartzite identical to those in the Swauger Formation are scattered through the section. The middle unit of interbedded quartzite and silty argillite, although not uniform throughout, is generally a sequence of thin-bedded, dark-purple and purplish-gray, silty argillite and fine-grained, platy-weathering, sandy siltstone layers, interbedded with medium- to thick-bedded and somewhat more resistant medium-reddish purple to light-pink impure to pure quartzite. In places the middle unit includes widely spaced thick beds of cross-laminated, light-pinkish-purple quartzite that are identical to the predominant lithology of the Swauger Formation. Many of the fine-grained, platy, impure quartzite beds are highly felspathic and have maroon argillite films on the bedding planes, micaceous partings, and mudchip breccias that have been formed by the disruption of the maroon argillite. The upper unit of thin-bedded and laminated argillite is composed of thin-bedded, dark-purplish-gray siltstone, argillite, and very fine grained dark-purplish sandstone or quartzite with a few widely spaced, cross-laminated, medium-thick beds of medium-grained quartzite. In general, the upper exposed part of the upper member is more argillaceous and contains much dark-purplish-gray well-laminated phyllite. Several beds, 3-10 ft thick, of a light-gray-green, siliceous mudstone or porcellanite occur in the upper 625 ft of the member.

ROCKS OF UNCERTAIN AGE

INTERBEDDED QUARTZITE, DOLOMITE, AND ARGILLITE OF LEATON GULCH AND PENNAL GULCH AREAS (ORDOVICIAN(?), CAMBRIAN(?), AND UPPER PROTEROZOIC(?))

A sequence of strata that may be in part of Late Proterozoic age is exposed over approximately 6 sq mi in the south-central part of the Challis 15-minute quadrangle (pl. 1), and in the northeast corner of the Lone Pine Peak 15-minute quadrangle (pl. 1). These are predominantly quartzite but contain subordinate dolomite interbeds and local intervals of thick argillite. The quartzite is generally deep red to dark purplish-gray to medium gray with some thick zones of light pinkish or tannish gray and light gray to white; medium grays and purplish grays predominate. Although most of these strata are thin to medium bedded, platy, and laminated, some units are massive, thick bedded, and structureless. Grain size is mostly medium to fine, but in places the rock is coarse and pebbly, and locally this unit includes several zones of coarse conglomerate or intraformational breccia. Much of the thin-bedded platy quartzite shows ripple marks, flute casts, worm trails, and abundant magnetite in parts of the section. The fine-grained dolomite is light to medium tan on fresh surfaces, weathers rich reddish tan to brown, and occurs as distinct beds that range from 0.5 ft to several yards in thickness. The dolomite is dispersed in the quartzite sequence and exposed 0.5 mi east of Beardsley Hot Springs (44°31′ N., 114°11′ W.). Argillite occurs as laminae or thin interbeds in much of the quartzite sequence and locally forms a continuous sequence as much as 300 ft thick. It is generally thin bedded, fissile, dark gray or purplish gray, and in places altered to deep gray green. Many argillaceous layers are metamorphosed to phyllite close to thrust faults.

The relation of the stratigraphic sequence to other Proterozoic units is indeterminate because of complex structure and discontinuity of exposures. However, the general characteristics of strata and structural relations to Swauger Formation suggest possible correlation with the Late Proterozoic Wilbert and (or) Lower Ordovician Summerhouse Formations (Ruppel and others, 1975) or with the formation of Tyler Peak of Early Cambrian age (McCandless, 1982).

ROOF PENDANTS

Roof pendants in the Idaho batholith, usually of small to moderate size, occur in the central and northwestern parts of the quadrangle. Most pendants are moderately to highly metamorphosed and their correlation with known Precambrian units is speculative. At least one isolated sequence in the upper Loon Creek drainage comprises schist, quartzite, and dolomitic marble that matches a well-dated unmetamorphosed Ordovician sequence of sedimentary strata in the Bayhorse area to the east. Graphite in small roof pendants in the central part of the quadrangle suggests a relation between those pendants and carbonaceous Paleozoic rocks in the southeast part of the quadrangle. The wide variety of rock types and variable degree of metamorphism exhibited by the roof pendants allows the possibility that some may have had Precambrian protoliths while others may be derived from Paleozoic rocks.

ORE DEPOSITS

Of the seven stratigraphic units within the Challis quadrangle that are of known or suspected Proterozoic age, only the Yellowjacket Formation and the Hoodoo Quartzite contain ore deposits that have been mined in the past. Extensive exposures of Big Creek, Apple Creek, and Gunsight Formations in the Lemhi Range to the east and southeast of the Challis quadrangle are the hosts for only a few small and scattered deposits, and no significant occurrences have been identified in the very limited exposures of these units in the Challis quadrangle. The Swauger Formation, although widely exposed in the Challis 15-minute quadrangle (pl. 1), is essentially barren, nor does it contain any deposits of any consequence throughout its very extensive exposures in the Lemhi Range. The only known exposures of the Lawson Creek Formation (Hobbs, 1980) along and near the eastern edge of the quadrangle contain no ore occurrences.

The Yellowjacket Formation and the closely associated Hoodoo Quartzite are hosts for a number of economically important deposits of gold, silver, lead, copper, and mercury. Stratiform cobalt-copper deposits at the well-known Blackbird mine 9 mi north of the quadrangle boundary might possibly have counterparts in the Iron Creek area where similar occurrences have been identified. In the Yellowjacket mining district considerable gold, silver, copper, and lead have been produced from the Yellowjacket Formation and the Hoodoo Quartzite. These metals occur in a predominantly quartz gangue in veins, irregular lodes, shear zones, stockwork, and breccia filling. The deposits have been roughly divided (Anderson, 1953) into gold-base metal deposits, silver-copper deposits, and silver-lead deposits, but with much gradation between the major minerals, which are gold (rarely visible to the eye), galena, chalcopyrite, and tetrahedrite. In addition to the major quartz, the gangue may include minor amounts of pyrite, siderite, and barite. Placer and eluvial gold eroded from the veins are the only other known deposits of economic value.

Distribution of the ore minerals in the veins, lodes, and stockworks is generally quite erratic, and ore-grade material may terminate abruptly in any direction. Such abrupt termination does not always mean the termination of potential, as new ore shoots have been found elsewhere along the veins. The Yellowjacket vein (44°59′ N., 114°31′ W.) has been productive over a vertical distance of nearly 500 ft. Mineralized outcrops of the nearby Continental-Columbia shear zone are exposed over a difference in elevation of 1,000 ft.

Discovery of the Yellowjacket lode in 1868 led to the location of more than a dozen properties in the Yellowjacket district. Of these, the Yellowjacket mine was by far the most productive and probably accounted for most of the total output. Total production of the district is not known because authentic records prior to 1893 are not available; records from 1893 to 1902 are only those from the Yellowjacket mine. Official records that include all operating properties for the period 1902 to 1949 are from the U.S. Bureau of Mines, as compiled by Anderson (1953) in his detailed report on the Yellowjacket district. During this 48-year interval a total of 3,855 oz of gold, 5,608 oz of silver, 20,792 lbs of copper, and 17,275 lbs of lead was produced. Intermittent but relatively small production from a few properties has been made from 1950 to the present. An unknown but relatively small amount of gold has been recovered from placer deposits in streams and terrace gravels along Yellowjacket Creek below the Yellowjacket townsite. A significant volume of gold-bearing eluvial material mantles the slopes below the outcrops of the Yellowjacket mineralized shear zone and has yielded an unknown but probably small production. This material is a possible future resource. Total metal production from the Yellowjacket district probably has exceeded $500,000 in value.

In the Yellow Pine-Big Creek area, straddling the boundary between the Challis and Elk City quadrangles about 40 mi west of the Yellowjacket mining district, extensive outcrops of sedimentary rocks and volcanic material that are considered to be of Proterozoic age and that have been tentatively correlated with the Yellowjacket Formation (B.F. Leonard, oral commun., 1984) are hosts for several types of ore deposits. Reports by Cooper (1951), Larsen and Livingston (1920), and Schrader and Ross (1926) give detailed descriptions of most of these deposits. The sedimentary and volcanic rocks have been extensively intruded by the Idaho batholith and are metamorphosed to greater or lesser degrees depending on their original composition and proximity to the contact. In a few places contact metamorphic ore deposits have been found, but most of these are small and sparsely mineralized. Major ore deposits in this district are the gold, silver, antimony, and tungsten ores in shear zones, breccias, and stockworks that have formed both in the batholith and in the pre-batholith sediments, and mercury-bearing silicified replacement deposits in the limestone-dolomite parts of the Proterozoic sedimentary sequence. Major past production has come from the Yellow Pine and Meadow Creek mines in which the ore bodies are in granitic host rock, but other similar deposits have been formed where shear zones have extended into strata that form the roof of the batholith. Mercury deposits that include the Hermes and Fern mines appear to have been controlled by the carbonate part of the stratigraphic section.

CARBONATE ROCK TERRANE

By S. Warren Hobbs

INTRODUCTION

Formations in which limestone, dolomite, or both are the dominant components are located for the most part in the southeastern quarter of the Challis quadrangle (pl. 2). A few minor occurrences are associated with the Precambrian strata along the northern border of the quadrangle and as small widely scattered roof pendants in the Idaho batholith and Tertiary plutons in the west-central part. Sand and silt are present as impurities in most of the carbonate strata, and interbeds of argillite, siltstone, and fine sandstone that range in thickness from thin laminae to tens of feet are a part of some formations. The distinction between sandy or silty carbonate formations and calcareous or dolomitic sandstone and siltstone is often arbitrary but usually depends on the dominant component.

Carbonate strata are found in several structural and stratigraphic environments and range in age from Proterozoic to Mississippian. Extensive exposures occur in the Bayhorse mining district that includes the major part of the Clayton 15-minute quadrangle, and in the Lone Pine Peak quadrangle to the east (pl. 1; fig. 3). Of the ten major carbonate formations that have been identified in these areas, only the Bayhorse Dolomite, the Ella Dolomite, and the Saturday Mountain Formation, all of which occur in the structurally complex Bayhorse mining district, have had significant production from ore deposits within the formations or closely related to them. The remaining carbonate formations in the Lone Pine Peak quadrangle, separated from those in the Bayhorse district by the Salmon River lineament (fig. 3) (Hobbs, 1985), include a thick sequence of predominantly limestone and dolomite units that range in age from Ordovician to Mississippian. Of these only the Ordovician Saturday Mountain Formation occurs on both sides of the Salmon River lineament.

The Salmon River lineament marks a structural break of major proportions that affects both the stratigraphy and the localization of ore deposits. In contrast to the carbonate rocks in the Bayhorse mining district that are well mineralized, the sequence east of the lineament has few mineral occurrences and no recorded production. The host rock control over the localization of ore deposits in carbonate strata in the Bayhorse and adjacent areas west of the Salmon River lineament depends on a combination of stratigraphic sequence, structural complexity, subjacent black shale units, and proximity to igneous intrusions that are not present or are hidden at depth on the east side of the lineament.

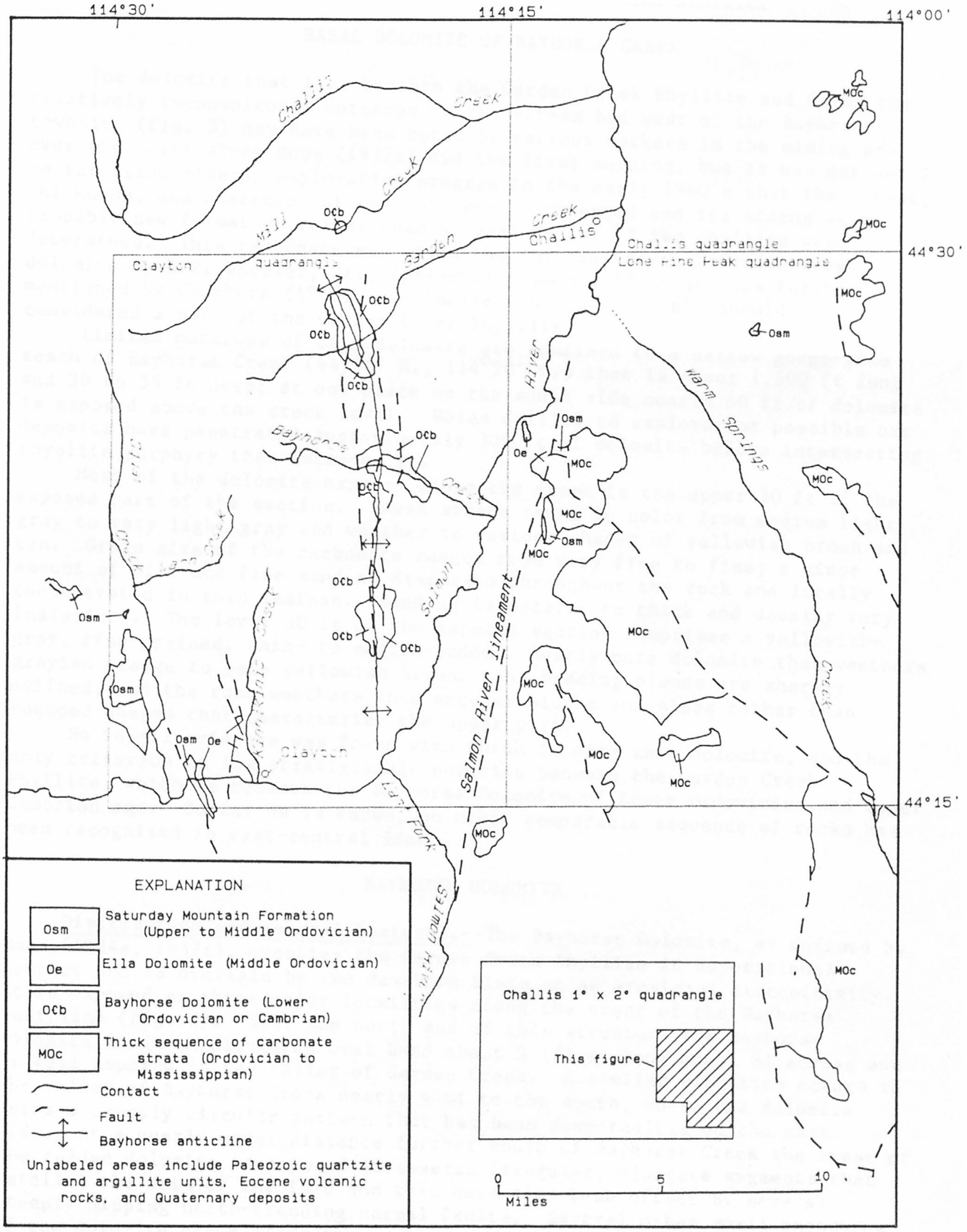

Figure 3. Generalized geologic map of the southeastern part of the Challis 1° x 2° quadrangle showing major units of carbonate rock terrane

CARBONATE ROCKS IN THE BAYHORSE MINING DISTRICT

BASAL DOLOMITE OF BAYHORSE CREEK

The dolomite that lies beneath the Garden Creek Phyllite and forms the relatively inconspicuous outcrops in the stream bed west of the Bayhorse townsite (fig. 3) may have been noted by various workers in the mining area over the years since Ross (1937a) did the first mapping, but it was not until an intensive mineral exploration program in the early 1960's that the extent, thickness, and character of the unit were documented and its status as a probable new formation rather than a local facies of the phyllite was determined. This carbonate was given the informal name of Garden Creek dolomite by D.P. Wheeler, Jr., (personal commun., 1964) and was further mentioned by Chambers (1966), who implied that it probably should be considered a part of the Garden Creek Phyllite.

Limited outcrops of this dolomite are confined to a narrow gorge-like reach of Bayhorse Creek (44°24′ N., 114°20′ W.) that is about 1,500 ft long and 30 to 35 ft deep; at one place on the south side nearly 60 ft of dolomite is exposed above the creek level. Holes drilled to explore for possible ore deposits have penetrated approximately 300 ft of dolomite before intersecting rhyolite porphyry that intrudes it.

Most of the dolomite exposed along the creek is the upper 30 ft of the exposed part of the section. These strata range in color from medium light gray to very light gray and weather to various shades of yellowish brown and tan. Grain size of the carbonate ranges from very fine to fine; a minor amount of silt and fine sand is dispersed throughout the rock and locally concentrated in thin laminae. Bedding is massive to thick and usually very indistinct. The lower 30 ft of the exposed section comprises a yellowish-gray, fine-grained, thin- to medium-bedded, nearly pure dolomite that weathers grayish orange to pale yellowish brown. The bedding planes are sharply defined, and the rock weathers into angular blocks and slabs rather than rounded shapes that characterize the upper part.

No fossil evidence was found with which to date this dolomite, and the only criterion is its stratigraphic position beneath the Garden Creek Phyllite, which is beneath the Bayhorse Dolomite of Lower Ordovician and Upper Cambrian age. So far as is known, no other comparable sequence of rocks has been recognized in east-central Idaho.

BAYHORSE DOLOMITE

Distribution and general features.--The Bayhorse Dolomite, as defined by Ross (1934a, 1937a), overlies the Garden Creek Phyllite in depositional contact and is overlain by the Ramshorn Slate on an erosional disconformity. It is exposed at three major localities along the crest of the Bayhorse anticline (fig. 3). Near the north end of this structure the Bayhorse Dolomite forms an elongated oval band about 3 1/2 mi long and 1 mi across and is well exposed in the valley of Garden Creek. A similar situation occurs in the valley of Bayhorse Creek nearly 4 mi to the south, where the dolomite forms a crudely circular pattern that has been down-faulted on the east side. At a nearly equal distance further south of Bayhorse Creek the crest of the folded dolomite is exposed in several irregular, elongate segments that parallel the axis of the fold and that have also been offset by several steeply dipping north-trending normal faults. Several other small exposures of the dolomite occur along the east limb of the main anticline where the overlying Ramshorn Slate has been stripped away. No other exposures correlative with the Bayhorse Dolomite are known to exist. The blanket of Eocene Challis Volcanic Group that extends for long distances on all sides beyond the mapped area, and the massive Idaho batholith to the west that intrudes the pre-Cretaceous strata, effectively prevent any direct tracing or projection of the unit within reasonable distances. Correlation with more remote carbonate sequences is hindered by the paucity of fauna in the Bayhorse Dolomite, by lack of any information on the age of the bounding units, by the unknown original thickness, and by any firm information on facies variation or depositional environment.

Character.--Early descriptions of the Bayhorse Dolomite emphasized a predominant dolomitic composition as the name implies (Ross, 1934a, 1937a; Anderson, 1954a). More recent work by Chambers (1966) refined the description and emphasized the fact that the unit is heterogeneous and includes appreciable amounts of limestone and shale. Further mapping of all known exposures of the Bayhorse Dolomite (Hobbs and others, in press) emphasized the diverse character of the unit, which not only comprises limestone and dolomite, but that also contains various amounts of both silt and sand as impurities in the form of dispersed grains and as concentrations in fine laminae or thin shale beds.

The lowest 300-400 ft of the Bayhorse Dolomite comprises predominantly thin-bedded limy strata, and the contact with the underlying Garden Creek Phyllite is gradational through a 50 ft zone of increasingly abundant thin slate interbeds. The middle 300-500 ft of section is a somewhat heterogeneous mixture of thin- to medium-bedded silty and fine-grained sandy limestone, dolomitic limestone, limy shales, and several nearly pure argillite or slate intervals.

Most of the strata in the upper 300 ft of the section, where measured on the north side of Bayhorse Creek, is a thick-bedded, almost massive, medium-dark to medium-light-gray, fine-grained dolomite that weathers in various shades of light brownish gray to orange gray. Several horizons in the upper half of the section are crowded with dark-colored, nearly black, siliceous ovoid bodies that are presumed to be oolites or pisolites and that range up to 0.2 in. in largest dimension. One especially distinctive oolite horizon occurs close below a laminated argillite interval, and together with the argillite interval has served as a key horizon for stratigraphic correlation. At least four intervals of nearly pure siltstone or argillite that range in thickness from 10 to 50 ft are dispersed within the central 400-500 ft of the exposed section. One of these argillite-siltstone members, located approximately 1,000 ft above the base of the formation, is a distinctive finely laminated rock that serves as a key bed in the mineralized area along Bayhorse Creek. In other places this member has been removed where the formation has been deeply eroded.

The amount and distribution of magnesium carbonate in the Bayhorse Dolomite raises questions as to its origin. Most of the massive, thick-bedded upper part of the unit is dolomite, which in most places makes up less than one-third of the exposed section. Elsewhere, especially in the general vicinity of the mineralized area, the thickness of dolomite or dolomitic limestone is greatly extended to include all but a few hundred feet of limestone at the base. Most if not all of the the upper contact zone, especially where disturbed, brecciated, or weathered on the paleo land surface, is dolomite, much of which appears to be recrystallized into a coarse-grained sandy dolomite. Dolomitization of predominantly limestone strata must be considered a probable origin for these beds.

Most of the early studies in the area recognized that the Bayhorse Dolomite was conformable with and gradational from the underlying Garden Creek Phyllite, that its upper contact with the overlying Ramshorn Slate was an erosional disconformity or low angle unconformity, and that an unknown amount of strata has been removed. The disconformity and the probable irregular uplift that exposed the Bayhorse Dolomite to erosion has resulted in a substantial variation in the thickness of this unit. A section measured on the north side of Bayhorse Creek in the west limb of the major anticline totaled approximately 1,800 ft. Chambers (1966, p. 25) measured 1,560 ft a short distance further west, and he reports thicknesses of 1,000 ft and 1,150 ft on Keystone Mountain about 3 mi to the north, and 1,100 ft on the north side of Garden Creek. Less than 500 ft has been reported elsewhere. In the light of such evidence of erosional destruction of the Bayhorse Dolomite within the relatively small area of its exposure, it is reasonable to suggest that the lack of any other known localities may be in part due to the total destruction of the section in adjoining terrane.

Over most of the area where the upper contact of the Bayhorse Dolomite is exposed, the carbonate strata below the contact have been affected in various ways and degrees by processes related to the pre-Ramshorn Slate erosion that produced an extensive karst terrane. Post-burial alteration, solution, and deposition by solutions moving through the highly permeable uppermost part of the carbonate sequence beneath the argillaceous beds of the Ramshorn Slate produced further changes. At the Pacific mine on the axis of the anticline north of the town of Bayhorse and west of Beardsley Gulch (44°25′ N., 114°19′ W.) the dolomite below the Ramshorn Slate is recrystallized, brecciated, and locally silicified for nearly 200 ft below the contact. In places within the mine workings that explore the dolomite are zones of massive breccia that resemble the collapse breccias in a karst region. Near Daugherty Gulch (44°29′ N., 114°20′ W.) on the northeastern end of the Bayhorse anticline, a highly silicified breccia is estimated to be 200 ft thick (Chambers, 1966, p. 30), whereas the same zone on the west limb of the anticline on upper Bayhorse Creek is very narrow or absent. The localization of many of the base metal sulfide and fluorspar deposits along, within, or parallel to this disturbed zone attests to its importance as a pathway for circulating ore-bearing solutions.

Age.--A definitive age for the Bayhorse Dolomite has been difficult to establish. Ross (1937a, p. 11 and 14) dated the unit as probably Upper Cambrian because of its position below the Ramshorn Slate which was then considered to be Lower Ordovician, and on the presence of dubious algal remains. Two recently discovered localities near the base of the formation east of the town of Bayhorse yielded several small fragments of ribbed brachiopod shells; a third locality near the same stratigraphic position but several miles to the north has produced two pelmatozoan columnals. Reports from a study of this material by R.J. Ross, Jr., and J.M. Berdan of the U.S. Geological Survey (written commun., 1969), and James Sprinkel of the University of Texas, Austin (written commun., 1971) concur that in spite of the equivocal results from the poorly preserved fossil material, the Bayhorse Dolomite is probably lower Paleozoic and most likely Lower Ordovician.

ELLA DOLOMITE

The name Ella Dolomite, first used informally by Patton (1948), was formally adopted by Hobbs, Hays, and Ross (1968) for a sequence of dolomitic strata at least 700 ft thick that lies in apparent conformity below the

Kinnikinic Quartzite near Clayton in the Bayhorse area. The general features, distribution, and characteristics of the Ella Dolomite are described below, and the distribution is shown on figure 3.

Distribution and general features.--Massive dolomite and sandy dolomite that make up the major exposures of the Ella lie below the Kinnikinic Quartzite and above the Clayton Mine Quartzite in the anticlinal structure along the Salmon River canyon west of the town of Clayton. The dolomite beds in this fold bend down sharply into the nearly vertical east limb of the anticline and form spectacular exposures along the west side of Kinnikinic Creek between a point near its mouth at the town of Clayton and the Clayton Silver mine about 1 1/2 mi upstream. These steeply dipping beds are the host rocks for the ore deposits in the long abandoned Ella mine near Clayton, and for the large replacement ore bodies at the Clayton Silver mine. Ella Dolomite is also exposed on the south wall of Salmon River canyon and along the west limb of the anticline where it forms a continuous band of outcrops southward from the river for several miles on the east side of the valley of Sullivan Creek ($44^{\circ}14'$ N., $114^{\circ}26'$ W.). Widely spaced outcrops occur east of and nearly parallel to the Salmon River from the East Fork of the Salmon River northward beyond the mouth of Bayhorse Creek.

Ella Dolomite has been definitely dated and delineated only in the Bayhorse area as described above. However, in the Pioneer Mountains east of Ketchum, Idaho, nearly 40 mi south-southeast of Clayton (Dover, 1981), and on Loon Creek about 30 mi northwest of Clayton, metamorphic sequences that occur as roof pendants or as wallrocks adjacent to the Idaho batholith contain white or light-tan granular dolomitic marble that is almost certainly equivalent to the type Ella Dolomite. In both places, the marble is overlain by a fine-grained quartzite that probably is Kinnikinic and underlain by a coarse-grained feldspathic quartzite that is in most respects analogous to the Clayton Mine Quartzite of the Bayhorse region.

Character.--The Ella Dolomite is predominantly medium- to thick-bedded dolomite, most of which contains some silt and fine sand, usually in thin laminae that on weathered surfaces show as fine ribbing or a hackly texture. This lamination is not obvious on fresh fractures. The dolomite is predominantly fine grained, but some parts as much as 25 ft thick are medium to coarsely crystalline. Color is generally medium to medium-dark gray, commonly with a brown or tan cast, but some layers are lighter gray, and some are dark gray to almost black. Weathered surfaces are predominantly tan, brown, or yellowish gray. Some layers near the base have a coarsely crystalline texture, dark-gray color, and weather to deep brown. This basal zone is distinctive and has proved useful as a marker bed.

Locally, about 230 ft above the base of the Ella, a 20- to 30-ft zone is more siliceous. Some layers in this zone consist of fine-grained quartzite, some of sandy dolomite, and some of chert that appears to have replaced other material. One highly silicified zone has an oolitic appearance that seems to have resulted from the replacement of subspherical algal structures by silica. Microlayered siliceous laminae are also believed to result from the replacement of algal structures.

Age.--Brachiopods and conodonts from a zone near the base of the Ella Dolomite and conodonts from the dolomite about 450 ft above the base were determined by R.J. Ross, Jr., and J.W. Huddle of the U.S. Geological Survey to be probably of early Middle Ordovician age; thus the Ella Dolomite is assigned to the Middle Ordovician.

SATURDAY MOUNTAIN FORMATION

The Saturday Mountain Formation, composed predominantly of limestone and dolomite, was named by Ross (1934a, p. 952) from a ridge in the southwestern part of the Clayton quadrangle on whose lower eastern slopes the strata are well exposed. In subsequent publications, Ross (1937a, 1962) further described the character, distribution, and age of the unit and speculated on its characteristics and the reasons for variation of thickness and facies. More recent work has resulted in minor refinements in distribution, general character, and age of the formation and has clarified the role of structure as related to facies changes.

Distribution and character.--In the Bayhorse area, the Saturday Mountain Formation is located along or near both sides of the lower reaches of Squaw Creek in the southwestern part of the Clayton quadrangle (fig. 3), and as small intermittent outcrops along a narrow north-trending zone within 1 mi east of the Salmon River lineament. Two small exposures east of the north end of this zone complete the known occurrences. The total exposed area of this unit is less than 6 sq mi, and at no place in the Bayhorse district is an uninterrupted stratigraphic sequence exposed because of the complex folding and faulting that has disrupted the region. However, a carefully measured section in the Lone Pine Peak quadrangle and east of the Salmon River lineament may represent nearly the total uninterrupted thickness (Hays and others, 1980). At this locality it is anomalously thin, contains no shale intervals as it does on Squaw Creek, and is interpreted to represent a drastic facies change across a major structural discontinuity that has telescoped sections of the formation that at one time were widely separated.

The base of the Saturday Mountain Formation in the Clayton quadrangle, where it can be studied along its contact with the underlying Kinnikinic Quartzite, is at least in part faulted and sheared subparallel to the contact, but there is no evidence of major disruption of the stratigraphic section. At several exposed contacts a black, sandy shale or siltstone is in sharp contact with the underlying clean, white Kinnikinic Quartzite, and contains a good fauna that has been identified as late Middle Ordovician (Hobbs and others, 1968). A short distance from the contact the shale and siltstone become slightly calcareous and weather into small plates and chips that are black on fresh surface but buff or yellowish gray when weathered. Within several hundred feet, the limy siltstone has become a silty dark-gray limestone that weathers into buff- or light-yellow-colored chips and plates, and includes increasing amounts of dark-blue-gray limestone that predominates toward the west end of the outcrop. Even though this lower part of the Saturday Mountain Formation is somewhat sheared and possibly faulted parallel to the contact with the Kinnikinic Quartzite, the general sequence strongly suggests a transition from black shale at the base through a fine sand or silty zone to an impure limestone over a distance of several hundred feet. More than 1,200 ft of platy, buff-weathering, medium-dark-gray, silty limestone and dolomitic limestone is exposed above the basal transition zone. This part of the section terminates against a vertical fault boundary.

Strata on both sides of the lower reaches of Squaw Creek are thought to lie above the basal part of the section, but their exact relation is indeterminate because of the extensive faulting and cover of Challis Volcanic Group and recent colluvium. Along the east side of Squaw Creek, about 3 mi from its mouth, is an indeterminate, but probably moderate thickness of a medium-bedded, dark-gray, erratically mottled, fine-grained, slightly fetid dolomite that contains scattered crinoid columnals and horn corals. This dolomite is locally laced with white carbonate veinlets and generally weathers to a dark-gray rather hackly or granular surface. Some fine sand and silt occurs as local impurities, but much of it is quite pure. Scattered carbonaceous material imparts the dark color. This interval of the Saturday Mountain Formation has many attributes of the Fish Haven Dolomite with which it is probably correlative (Churkin, 1963).

Strata of Ordovician age that lie above the black fetid dolomite are best exposed west of Squaw Creek and on the north side of Bruno Creek (fig. 3) along the stretch that trends westward from its mouth, and on the conical hill that is bounded by Squaw Creek on the east and by Bruno Creek on the south and west. The lowest outcrop is a resistant ledge of dolomitic quartzite as much as 30 or 40 ft thick that is overlain by a few feet of black crystalline dolomite. Above the dolomite is a black, fissile and brittle shale that contains a well-preserved graptolite fauna of late Middle Ordovician age. The fossiliferous black shale zone, about 20 ft thick, grades upward into a medium-dark-gray to light-grayish-green, fissile and somewhat calcareous shale and siltstone that is approximately 200 ft thick. The limy shale and siltstone interval changes abruptly across a vertical fault at its upper boundary into an intermixed sequence of medium- to thin-bedded, medium-dark to light-gray, fine-grained dolomite that contains variably spaced thin beds, or strings of elongate pods or lenses, of light-gray and medium-gray chert. This part of the section is estimated from map measurement to be about 2,000 ft thick but may be overly thickened by faulting. West of the crest of the conical hill, the cherty dolomite is overlain by a considerable thickness of laminated, dark-blue-gray and olive-gray to buff-colored, slightly impure to shaly, fine-grained limestone. This limestone part of the unit weathers to chips and small platy fragments that are buff or light yellow colored. Some platy layers split into nearly paper-thin sheets along the bedding. Good exposures occur at road level along Bruno Creek. The thickness of this limestone is more than 1,000 ft.

Even though the variety of rock types that make up the Saturday Mountain Formation in the Squaw Creek area of outcrop add up to a composite thickness of over 4,000 ft, the abundant evidence of complex folding, thrust faulting, and normal faulting makes such an estimate suspect, and the above descriptive sequence is open to alternative interpretation.

Age.--The thick section of Saturday Mountain Formation along Squaw Creek has yielded identifiable faunas from numerous localities that give ages ranging from late Middle to Late Ordovician. As mentioned above, the extensive disruption of the section by folding and faulting precludes the reconstruction of a definitive and continuous stratigraphic section, but the variety of lithologies from which ages have been obtained and the subtle variation in the ages as interpreted from the faunas make it plausible to infer that this section is reasonably complete and probably includes all of the Upper Ordovician. Some latest Middle Ordovician and Lower Silurian may be included. The thinner section of nearly continuous carbonate strata studied by Hays and others (1980) in the Lone Pine Peak quadrangle has yielded numerous fossil collections that give an age of late Middle through Late Ordovician. The upper part may be Silurian.

UPPER CARBONATE OF CASH CREEK

Two exposures of dolomite, each less than one-tenth square mile in area, occur east and west of Squaw Creek about 7 mi north of the Salmon River. One exposure is about 1/2 mi west of Squaw Creek from a point nearly 1 mi south of the mouth of Cash Creek (fig. 3). The other and larger is east of Squaw Creek and on the north side of Cash Creek about 2 mi above its mouth. Although only the eastern outcrop is dated from fossil evidence to be Ordovician, the western outcrop is considered to be correlative on the basis of stratigraphic similarities and structural position. These dolomites may be related to either the Saturday Mountain Formation or the Ella Dolomite.

CARBONATE SEQUENCE EAST OF THE SALMON RIVER LINEAMENT

Strata in this part of the carbonate terrane are largely of middle and upper Paleozoic age and represent parts of the stratigraphic sections that are mostly absent west of the Salmon River lineament. The stratigraphic section exposed east of the Salmon River lineament here is generally younger and better known than that to the west, and is an extension of the stratigraphy studied in the Lost River Range by Ross (1947) and Mapel and others (1965). Geology of this terrane differs from that in the others in three significant ways--different facies and ages of the strata, structural style, and regional trends.

The Saturday Mountain Formation that has its type section in Squaw Creek is represented east of the Salmon River lineament by significantly different facies and thicknesses. Above this facies of the Saturday Mountain Formation the Paleozoic section comprises the Roberts Mountain Formation and "Laketown Dolomite" of Silurian age, the Beartooth Butte and overlying unnamed dolomite units, the Jefferson Dolomite, Grandview Dolomite, and Three Forks Formation, all of Devonian age, and the McGowan Creek, Middle Canyon, and Scott Peak Formation of Mississippian age.

RELATION OF CARBONATE ROCK TERRANE TO ORE DEPOSITS

In the carbonate terrane west of the Salmon River lineament, significant replacement ore bodies containing base and precious metals have been developed in the Bayhorse Dolomite, the Ella Dolomite, and the Saturday Mountain Formation. The Bayhorse Dolomite is the host rock for the lead, zinc, silver, and fluorite deposits at the Pacific mine in the Bayhorse district, the lead, silver, and zinc replacement ore bodies at the Riverview and Beardsley mines of the same district, and the fluorite deposits in the brecciated disconformity at the top of the Bayhorse Dolomite on Keystone Mountain. Numerous small mines and prospects of similar modes of occurrence are scattered through the known areas of outcrop of these dolomitic and calcareous rocks. The Ella Dolomite, although of very limited exposure, contains the extensive lead, silver, and zinc replacement ore bodies of the Clayton Silver mine, the occurrence of possibly important ore deposits at the Rob Roy mine area nearby, and the ore deposit at the long abandoned Ella mine--all on Kinnikinic Creek. Widespread dolomite, limestone, and impure carbonaceous dolomite and limestone of the Saturday Mountain Formation along the valley of Squaw Creek are the host rocks for the extensive lead-silver replacement deposits at the Red Bird mine that were modified and probably enriched by deep oxidation, and the vein and replacement deposits in shear zones in impure dolomite at the Dryden mine on Sullivan Creek. Several other small mines and prospects are located along steep faults that cut this unit.

In several localities, the carbonate strata within which the ore bodies are developed are underlain by thick sections of black shales and siltstone. These black argillaceous rocks have been proposed as the source rock for veins and stratabound deposits within the black shales themselves (Hall and Hobbs, this volume, p. 29) and also could logically be considered a source for many of the replacement deposits in the overlying carbonate units. The basic mineralogy for both the black shale deposits and the carbonate replacement deposits is strikingly similar. Steep faults are in close association with the ore bodies at all known occurrences of replacement ore deposits in carbonate rocks.

The thick, widespread carbonate stratigraphy east of the lineament is notably barren of the metalliferous ore deposits that characterize the Bayhorse district to the west. This lack of ore deposits may result from a combination of such factors as a drastic change in lithologies across a structural discontinuity, lack of igneous intrusion, paucity of black shale source rock, or unfavorable structural controls.

BLACK SHALE TERRANE

By Wayne E. Hall and S. Warren Hobbs

The south-central part of the Challis quadrangle is underlain by highly mineralized, black, siliceous-facies, clastic sedimentary rocks of Late Cambrian to Permian age. This black shale terrane is approximately 12 mi wide in an east-west direction between the Yankee Fork of the Salmon River and the Bayhorse district, and extends from the south border of the Challis quadrangle to between 6 and 17 mi north of the Salmon River (fig. 4). It extends south from the Challis quadrangle 57 mi through the Wood River area to the latitude of Bellevue, Idaho.

GEOLOGIC SETTING

The geology and mineral deposits of this belt have been described by Ross (1937a), Tschanz and others (1974), Hall (1985), and Hobbs (1985). The sedimentary rocks are predominantly black, fine-grained argillite, siltite, limy sandstone, siltstone, shale, fine-grained quartzite, and micritic limestone. All of the Paleozoic formations are allochthonous and occur in imbricated structural plates separated by major thrust faults. The structural plates are stacked with predominantly younger Paleozoic sequences over older, and the sequences progress from youngest on the west to oldest on the east. All of the formations are tectono-stratigraphic units with neither the top nor base exposed. Different formation names are applied to essentially coeval rock units in separate thrust plates, if the lithology, internal structures, and degree of sorting, roundness, and composition of clasts make each unit sufficiently distinctive so it can be mapped separately. In this paper the term "formation," for example Wood River Formation, is used to describe the lithologies, textures, or structures of a stratigraphic sequence of rocks within a tectono-stratigraphic unit. The term "allochthon" is used to refer to the body of rocks within a tectonostratigraphic unit bounded by thrust faults. For example, the sequence of rocks (the formation) may be intensely deformed internally within the allochthon, but the allochthon may be gently deformed into broad, open folds.

The black shale terrane is divided into two sub-terranes separated by a 7-mi-wide belt of Ordovician and Cambrian(?) quartzites and carbonates of the carbonate terrane (fig. 4). The Bayhorse sub-terrane, on the east, includes the Bayhorse mining district and is composed of Lower Paleozoic rocks. The White Cloud Peaks sub-terrane, on the west, is composed of younger Paleozoic rocks.

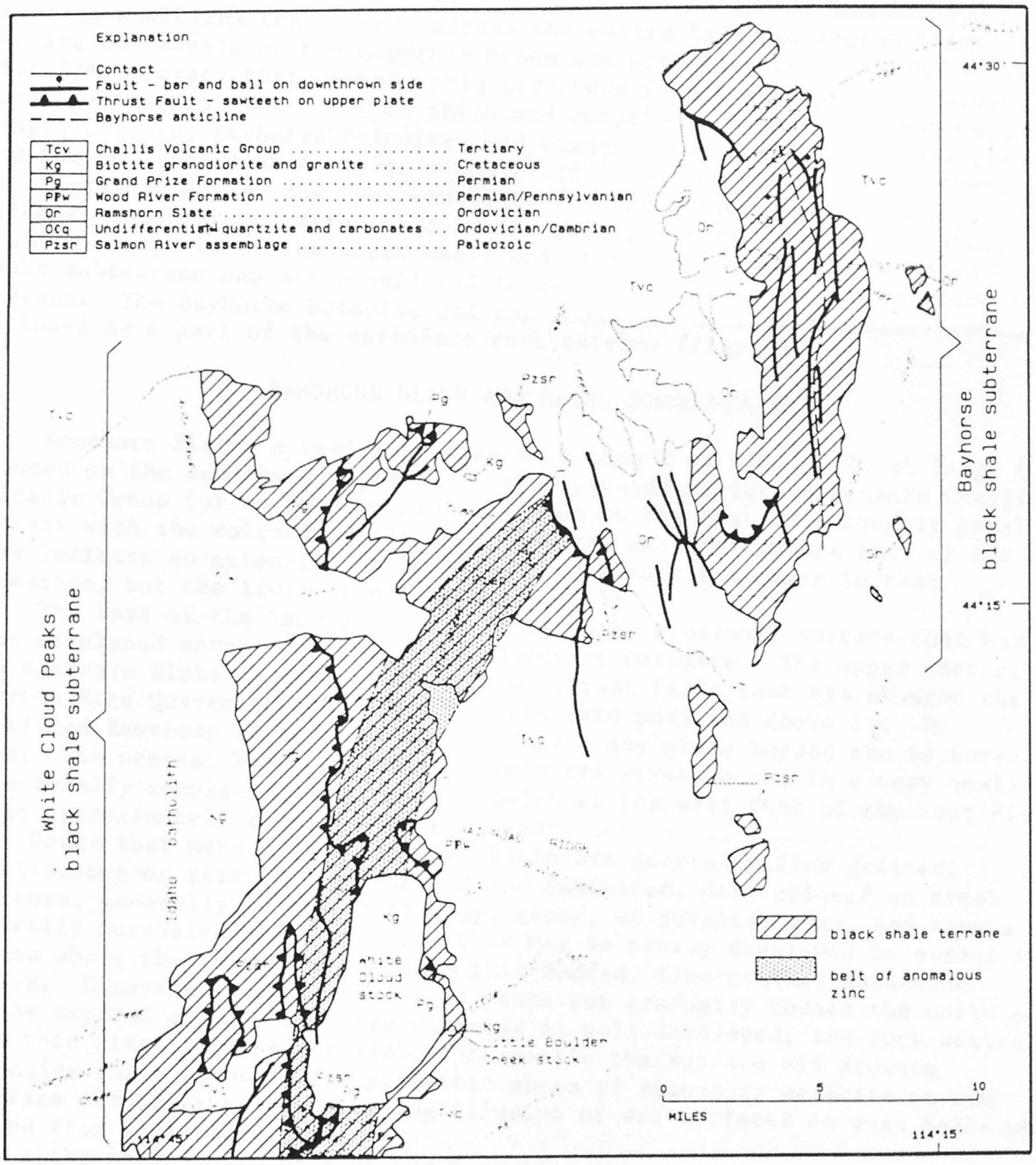

Figure 4. Map showing geology of central Idaho black shale terrane in the Challis 1° x 2° quadrangle

BAYHORSE SUB-TERRANE

The Bayhorse district is underlain by an allochthonous sequence of undated strata of probable Early Ordovician and Late Cambrian age. These strata include four lithologic units that form the core of the massive Bayhorse anticline that trends across the entire Bayhorse region (figs. 3, 4), and are the locale of the numerous mines and prospects of the Bayhorse mining district. Strata that compose this structure form a generally concordant sequence that is over 5,000 ft thick and comprises, from top to bottom, the Ramshorn Slate, Bayhorse Dolomite, and Garden Creek Phyllite of Ross (1934), and the informally named lower dolomite of Bayhorse Creek. Two of these stratigraphic units, the Ramshorn Slate and the Garden Creek Phyllite, although interlayered with the dolomite units, are analogous in physical and chemical respects to the black shale and siltstone strata of the White Cloud Peaks subterrane and are considered to be an integral part of the black shale terrane. The Bayhorse Dolomite and the lower dolomite of Bayhorse Creek are included as a part of the carbonate rock terrane (fig. 3).

RAMSHORN SLATE AND BASAL CONGLOMERATE

Ramshorn Slate, covering an area more than 2 mi wide by 20 mi long, is bounded on the west by a major fault that extends northward beneath Challis Volcanic Group for an unknown distance, and on the east by a roughly parallel contact with the volcanics (fig. 4). Several small exposures east of the main mass indicate an extension of the Ramshorn beneath the cover in that direction, but the limit is not known.

The base of the Ramshorn Slate rests on an erosional surface that has been developed across the underlying Bayhorse Dolomite. The upper contact of the Ramshorn Slate is everywhere a major thrust fault that has brought the Clayton Mine Quartzite and related strata into position above it. No confirmed Ramshorn Slate has been recognized any place beyond the Bayhorse area. The nearest known possible correlative strata occur in a very small structurally complex area in Sawmill Gulch at the west foot of the Lost River Range approximately 25 mi to the southeast.

Rocks that make up the Ramshorn Slate are generally fine grained, argillaceous or silty, thinly banded and laminated, dark colored on fresh fracture, generally in shades of gray, green, or purplish gray, and have a generally pervasive slaty cleavage that may be poorly developed or absent in places where the formation includes thin-bedded, fine-grained sandstone layers. Cleavage intensity seems to phase out gradually toward the north end of the exposed area. Where the cleavage is well developed, the rock weathers into thin plates, chips, or slabs that mantle the surface and produce extensive talus slopes. The phyllitic sheen of secondary sericite on the cleavage planes gives the striking illusion of wet surfaces on such talus when viewed from a distance.

Although the main mass of the formation is composed of thinly banded argillaceous and silty rock, a locally developed thick basal conglomerate belt that trends west-northwest occurs in Daugherty Gulch (44°29′ N., 114°20′ W.) and Garden Creek, and probably is a channel filling of one of the major streams that flowed across the erosion surface on which the Ramshorn was deposited. To the north and south, the conglomerate interfingers with fine sand and siltstone that are part of the lower Ramshorn lithology. Several small occurrences of pebble conglomerate in the upper part of Rattlesnake Creek (44°21′ N., 114°20′ W.) and near the east edge of Poverty Flat (44°19′

N., 114°22′ W.) may represent the general basal zone of the Ramshorn but are probably not directly related to the main channel conglomerate farther north.

The general structure of the Ramshorn Slate conforms to the large anticlinal fold that involves all four of the interstratified black shale and massive carbonate units. Moderately dipping limbs at the southern end of the anticline show it to be generally symmetrical, but the northern part, including exposures in the Bayhorse and Garden Creek areas, is more compressed with near vertical dips on the east limb and a faulted and irregularly dipping west limb. The competent Bayhorse Dolomite and probably the lower dolomite of Bayhorse Creek were folded and locally faulted and fractured but not intensely deformed. In contrast, both the Ramshorn Slate and the Garden Creek Phyllite are generally much contorted, locally drag folded, and cut by axial plane cleavage that is everywhere a part of the pervasive cleavage mentioned above.

An original thickness for the Ramshorn Slate is difficult to establish because of the internal folding, the lack of definitive key horizons, the pervasive cleavage, and the faulted top, but we estimate it to be at least 2,400 ft.

GARDEN CREEK PHYLLITE

The Garden Creek Phyllite, named by Ross (1934a), underlies the Bayhorse Dolomite and is exposed for 2.5 mi^2 along the canyon walls in the core of the Bayhorse Anticline in Bayhorse Creek, and to the north in the valleys of Garden Creek and Daugherty Gulch.

The formation is composed exclusively of dark-gray or nearly black phyllite with abundant silvery sericite on cleavage surfaces. Some of the phyllite is slightly calcareous. The rock is soft and weathers so readily that observable exposures are rare.

Most of the argillite beds are 1 to 15 mm thick, and the grain size ranges from clay to silt. Interbeds of fine sand up to several feet thick have been found in a few places. Unaltered argillite from mine workings is reported by Chambers (1966) to be "dead black and to stain the fingers with impalpable soot." Marcasite is a common constituent of the black shales and a faint odor of hydrogen sulfide pervades old mine workings. The fine grain size, dark carbonaceous constituents, and iron sulfide content are hallmarks of an anaerobic black shale environment that is generally inhospitable to living organisms and could be the major factor for their absence as fossil remains in the rock.

Bedding, where it can be identified, is in many places intensely crumpled, and the axes of small folds may plunge either north or south. The cleavage strikes consistently within a few degrees of north, generally parallel to the axis of the regional anticline. Cleavage dip is mostly steep. Internal structures of the Garden Creek Phyllite reflect adjustment by flowage, drag folding, and axial plane cleavage of an incompetent, thick, argillaceous unit that has been folded between competent carbonate sequences.

An estimated 1,200 to 1,400 ft of the phyllite is included between the base and the top of the unit, where these contacts are exposed on the north side of Bayhorse Creek, 2,000 ft west of the Bayhorse townsite; slightly more is exposed on the south side. However, the internal folding and flowage of the phyllite assure that the original thickness was much less.

WHITE CLOUD PEAKS SUB-TERRANE

The White Cloud Peaks sub-terrane is an area of about 150 mi^2 in the south-central part of the Challis quadrangle along the east side of the Idaho batholith (fig. 4). It continues south into the Hailey $1^\circ x2^\circ$ quadrangle for 60 mi. On the north it is covered by Challis Volcanic Group, but it probably extends under the volcanics 16 mi to the northwest where it is present in small outcrops along the east border of the Idaho batholith. Rocks that make up the White Cloud Peaks sub-terrane are the Salmon River assemblage, Wood River Formation, and Grand Prize Formation (fig. 4).

SALMON RIVER ASSEMBLAGE

The Salmon River assemblage is the structurally lowermost allochthon exposed in the White Cloud Peaks sub-terrane (fig. 4). Neither the base nor the top of the assemblage is exposed. The allochthon has been thrust from the west over Ordovician and Cambrian(?) carbonate and quartzite sequences on the east that underlie the Clayton Silver mine area (fig. 4). The upper contact is a thrust fault with overlying Wood River allochthon on the southeast and the Grand Prize allochthon on the west (fig. 4). These strata previously were mapped as part of the Milligen Formation by Ross (1937a) and Kern (1972) and as an unnamed argillite, quartzite, and limestone unit of Mississippian and Devonian(?) age by Tschanz and others (1974). Nilsen (1977) recognized that these strata formed a thick sequence of quartzite, limestone, calcareous siltstone, and fine-grained sandstone turbidites interbedded with abundant argillite; he used the informal name Salmon River sequence and assigned a Late Mississippian age.

Strata of the Salmon River assemblage consist of interbedded dark-gray to nearly black argillite, calcareous siltstone, micritic limestone, siltite, fine-grained quartzite, and relatively pure medium-gray limestone that commonly contains tremolite. Clean limestone is most abundant in the upper part of the sequence at the Hoodoo mine and in Washington Basin. Thin beds of highly carbonaceous micritic limestone are interbedded low in the sequence. Fine-grained pyrite, pyrrhotite, and locally sphalerite are disseminated in the carbonaceous argillites and micritic limestones. Bedding thickness ranges mostly between 2 and 18 in. and sedimentary textures and structures include graded beds, local cross beds, laminations, scour, sole markings, and local convolute structures produced by syndepositional slumping. The less competent beds, the argillites and calcareous siltstones, have a prominent fracture cleavage. The competent fine-grained quartzite beds in places are shattered to form beds or lenses of tectonic breccia. Pods of tectonic breccia crop out most commonly along ridges as the breccia is commonly silicified and is very resistant to erosion. The breccias form where quartzite is interbedded with incompetent carbonaceous limestone. Apparently, the breccia formed when the quartzite bed was flexed during a period of thrusting and the adjacent limestone was highly contorted by plastic flow. These pods of tectonic breccia are common in the Salmon River assemblage north of Silver Rule Creek (44°11′ N., 114°35′ W.) and west of Mill Creek (44°14′ N., 114°33′ W.).

Within 2 mi of the contact with the Idaho batholith, the Salmon River assemblage has undergone widespread contact metamorphism. The rocks are bleached and metamorphosed to siltite, fine-grained quartzite, hornfels, and calc-hornfels, and are locally silicified.

The thickness of the Salmon River assemblage is difficult to estimate. The beds strike north to N. 30° W. and dip 60°-80° W., and graded bedding, where observed for 4 mi in the eastern part of the allochthon along the Salmon River, indicates tops are to the east. The crest of an overturned anticline is present along Slate Creek. Assuming no other folds on the overturned east limb of the anticline, the indicated thickness of Salmon River assemblage is approximately 20,000 ft. This thickness seems excessive and may result from unrecognized isoclinal folds as well as duplication of section by faults. West of Slate Creek, along Last Chance Creek (44°12′ N., 114°37′ W.), the Salmon River assemblage is about 6,000 ft thick, but the top of the sequence there is marked by a thrust fault and the bottom of the section is not exposed.

The Late Mississippian age of the Salmon River sequence (Nilsen, 1977) was based on two collections of fossils derived from float material discovered at two localities. One of these faunas was in a single, semi-rounded float block that was collected in a gulch on the north side of the Salmon River opposite the mouth of Slate Creek, near the southern edge of the Thompson Creek 7 1/2-minute quadrangle (pl. 1). This material (USGS loc. no. 24408-PC) was examined by J.T. Dutro, Jr., in consultation with W.J. Sando, who reported (written commun., 1971) that "This collection is Mississippian in age, most probably middle or Late Mississippian. The large fragment of the spiriferoid brachiopod, Anthracospirifer, is most useful because that genus is now known to range from late Early Mississippian to Middle Pennsylvanian. Other elements of the fauna, though not diagnostic, are compatible with the Mississippian age assignment."

Conodonts from the same material were studied by John W. Huddle (written commun., 1971) who reported that several diagnostic species "occur with Apatognathus in the upper part of the St. Louis Limestone in the Mississippi Valley. This collection could be as old as late St. Louis time or as young as early Chester (Late Mississippian) time." An abundant calcareous foraminiferal fauna was reported by Betty Skipp (written commun., 1971) to be "a middle Visean (late Meramec) fauna which represents F.Z. 13-15 of the Mamet Foraminiferal zonation. These zones are present in the St. Louis and Ste. Genevieve Limestones of the midcontinent region; the fauna is typical of the lower part of the Scott Peak Formation of south-central Idaho (Mamet and others, 1971)." Although the stratigraphic section on the ridge above this specimen locality contains widely scattered carbonate beds in the predominantly argillite-siltite sequence, no fossils were found in place. The closest known fossil-bearing carbonate section of comparable age is the Scott Peak Formation, which is exposed in the southeast corner of the Bayhorse area (fig. 3).

A second faunal locality, located in the lower part of Mill Creek near the northern edge of the Livingston Creek 7 1/2-minute quadrangle (pl. 1), comprises a large, angular float block that contains an abundant megafauna (USGS loc. no. 27036-PC). This specimen, found approximately 1 mi southeast of the locality opposite the mouth of Slate Creek, is roughly at the same stratigraphic horizon and of similar age. It has also been reported on by J.T. Dutro, Jr. (written commun., 1979), who stated, "The excellent silicified fossils are identifiable as an assemblage characteristic of Upper Mississippian strata in the northern Rocky Mountains. The assemblage is of probable late, but not latest, Chesterian age, approximately a correlative of Mamet Foraminiferal Zone 18. Beds of about this age occur also in the Surrett Canyon Formation of Idaho, the Horseshoe Shale Member of the Amsden Formation of Wyoming, and the big Snowy Group of central Montana. The most diagnostic species is Anthracospirifer shawi shawi Gordon, which occurs in Zone 18 equivalents in Wyoming (Gordon, 1975)." No similar material has been located in place in undisturbed outcrops.

Subsequent sampling of several well-defined carbonate and calcareous sandstone and siltstone horizons at five localities within the predominantly siltstone and calcareous siltstone Salmon River lithologies has produced conodonts whose ages range from Late Cambrian to Late Devonian. Two of these localities have been collected by F.G. Poole, W.E. Hall, and S.W. Hobbs in the lower reaches of Thompson Creek in the Thompson Creek 7 1/2-minute quadrangle (pl. 1). The first locality (USGS 11020-SD), located on the west bank of Thompson Creek about 2 mi above its mouth, was reported by J.E. Repetski to contain conodonts of Late Devonian age. The second locality, about 1/2 mi south of the first and on the same side of Thompson Creek, includes three samples, two of which were collected by Poole and Hall (USGS loc. nos. 9851-CO and 9852-CO), and the third by Hobbs (USGS loc. no. 9618-CO). Conodonts from these three collections were studied by J.E. Repetski who reported that two were of Late Cambrian age and the third "Most likely Latest Cambrian to Earliest Ordovician." Samples from outcrops in a road cut on State Highway 75 about 1.1 mi west of the mouth of Thompson Creek were collected by F.G. Poole (USGS loc. nos. 10736-SD and 10737-SD) and examined by Anita G. Harris who reported them to be Middle Devonian. The remaining two known localities occur in the lower valleys of Sheephead Creek (44°12′ N., 114°36′ W.) and Last Chance Creek (44°12′ N., 114°37′ W.) that are west-side tributaries to Slate Creek at approximately four and five miles, respectively, above its junction with the Salmon River, and in the west-central part of the Livingston Creek quadrangle. The sample from Sheephead Creek was collected by Poole and Hall (USGS loc. no. 11021-SD) from detrital limestone float blocks on the north side of the valley and less than 1/2 mi above its junction with Slate Creek, and reported by J.E. Repetski to have an age of "Middle Ordovician to Middle Devonian." Similar material from the north side of Last Chance Creek about 1,000 ft above its junction with Slate Creek is reported by Repetski to be Late Devonian.

Several aspects of the Salmon River allochthon--the presence of widely different ages of strata, the documented structural complexity, and the variations in lithologic character--make the use of the word "sequence" as applied to these strata inappropriate. For this reason, Hobbs (1985) proposed that the strata that comprise this allochthon be called the Salmon River assemblage. No connotation as to origin is implied. The fossil evidence described above so poorly constrains the time of deposition of the rocks that Fisher and others (in press) have assigned a Paleozoic age to the entire assemblage.

WOOD RIVER FORMATION

The Wood River Formation crops out over an area of about 8 mi^2 in the White Cloud Peaks along the east side of the White Cloud stock from Railroad Ridge south to the border of the Challis quadrangle (fig. 4). The formation extends south of the Challis quadrangle throughout the Wood River Valley region. The Wood River Formation has been described by Hall and others (1974), who divided the formation into seven units that have a stratigraphic thickness of about 9,800 ft. Unit 6 is the only unit present in the Challis quadrangle except at the west end of Railroad Ridge, where a small area is underlain by units 1 to 4. Unit 6 is the host rock for the molybdenum porphyry deposit at Little Boulder Creek, and for the lead-silver vein deposits in the Galena district and Boulder Basin a few miles south of the Challis quadrangle.

The Wood River Formation on Railroad Ridge consists of several small boudins of siliceous conglomerate, which correlate with unit 1, that are present in the thrust fault zone between the underlying Salmon River assemblage and the Wood River Formation at the Little Livingston and Hermit mines. The thrust fault zone is a 10- to 25-ft-thick highly brecciated and bleached zone that locally contains highly silicified gossan. It is overlain by approximately 600 ft of gray, pink-weathering limy siltstone, gray sandy limestone, and gray fine-grained limy sandstone. This lithology correlates with units two, three, and four of the Wood River Formation at the type locality at Bellevue (Hall and others, 1974).

The Wood River Formation on the south side of Washington Basin (44°01′ N., 114°39′ W.), in Chamberlain Basin (44°02′ N., 114°37′ W.), and on the east side of the White Cloud stock is a medium-bedded, fine-grained, gray, limy sandstone that contains poorly preserved fusulinids in many places. The lithology and abundance of fusulinids suggests it all correlates with unit 6. Along the east side of the White Cloud stock, for example at the Little Boulder Creek molybdenum deposit (pl. 1), the limy sandstone has been contact metamorphosed to a dense green siliceous calc-silicate rock that is the host rock for molybdenite and scheelite. Fossil identification of some poorly preserved fusulinids verify the field assignment to unit 6. Four collections of fusulinids were made from the head of Grand Prize Canyon (43°56′ N., 114°41′ W.) in the Horton Peak 7 1/2-minute quadrangle about 4 mi south of the Challis quadrangle in a southerly extension of the same belt of Wood River Formation. R.C. Douglass (written commun., 1979) states that these samples contain specimens of Triticites sp. and Schwagerina sp. and confirm the assignment to unit 6. They represent the upper part of unit 6 (Wolfcampian) of Lower Permian age.

GRAND PRIZE FORMATION

The Grand Prize Formation was named by Hall (1985) for a thick sequence of medium- to dark-gray siltite, fine-grained quartzite, siltstone, and medium- to dark-gray sandy and silty limestone that is well exposed south of the Challis quadrangle in the Horton Peak 7 1/2-minute quadrangle on the north side of Pole Creek at the confluence with Grand Prize Creek. The formation crops out in the Challis quadrangle in a belt 3-6 mi wide between the Salmon River assemblage on the east, the Idaho batholith on the west, and the Wood River Formation on the southeast. It extends south in the Hailey quadrangle approximately 12 mi to near the head of the Salmon River. The formation is the structural highest tectonostratigraphic sequence in the central Idaho black shale belt. The formation is divided into four informal units that total 4,757 ft in thickness (Hall, 1985). The lower unit is gray, sandy limestone with abundant crossbedding and convolute structures overlain by dark-gray siltite and limy siltite in the upper part. The next unit is a gray silty limestone, 98 ft thick, that contains abundant fossil debris. It is overlain by a banded gray, limy siltstone and siltstone unit that is in part metamorphosed to hornfels and calc-hornfels and contains abundant crossbedding and convolute structures. The upper unit is a dark-gray siltite that weathers dark red and reddish brown. Grains of pyrrhotite are abundantly disseminated in the host rock, except where they are recrystallized to 1- to 2-mm clots.

The age of the Grand Prize Formation is Early Permian (Wolfcampian and (or) Leonardian) and Pennsylvanian(?) based on conodont identifications by Bruce Wardlaw and Anita Harris reported in Hall (1985).

Bedding in the Grand Prize Formation strikes northerly and dips steeply both east and west. The formation is deformed into tight isoclinal folds that are overturned toward the east. Folding occurred prior to or during early stages of thrusting as many steep isoclinal folds are truncated by the flat-lying sole thrust zone, for example, at the Hoodoo mine (pl. 1) and on the north side of Washington Basin.

At many places the contact between the Grand Prize allochthon and the underlying Salmon River allochthon is a zone as much as 984 ft thick of tectonic breccia. Good exposures are present in Slate Creek at the upper workings of the Hoodoo mine, and on the north slope of Washington Basin ($44^{o}01'$ N., $114^{o}39'$ W.), and continuing to the north into the Fourth of July Creek drainage ($44^{o}03'$ N., $114^{o}39'$ W.). This tectonic breccia in the Boulder Mountains is the unit that was originally described by Thomasson (1959) as Hailey Conglomerate of Middle Pennsylvanian age. However, the breccia differs in lithology, structural setting, and age from the type Hailey Conglomerate. The breccia lies within a regional thrust fault zone between the Salmon River assemblage and the overlying Upper Pennsylvanian(?)-Lower Permian Grand Prize Formation. The breccia zone forms bleached, resistant outcrops that locally cut across bedding in both the overlying and underlying allochthons. Clasts in the breccia are mostly angular but locally are rounded. They exhibit a pronounced structurally aligned fabric in which clast boundaries grade into recrystallized sheared siliceous matrix. Locally, remnant sedimentary bedding structures in breccia clasts or boudins are truncated by shears. The clasts are argillite and siltite, lithologically and texturally similar to the matrix material. Locally, the matrix is sheared and recrystallized limestone. Field relationships and petrographic studies indicate that this is a tectonic breccia derived primarily from the Salmon River assemblage and is not equivalent to the Hailey Conglomerate. It was formed when the Grand Prize allochthon was thrust to the east upward and over a topographic high formed by the underlying Salmon River allochthon. Many small Cretaceous and Tertiary granitic plutons have intruded laterally along this tectonic breccia zone. While doing so, they bleached and contact-metamorphosed the breccia and locally formed mineral deposits within the breccia zone or in steep faults below it.

ORE DEPOSITS

The black shale terrane is highly mineralized and contains deposits of antimony, arsenic, barite, fluorite, gold, lead, molybdenum, silver, tin, tungsten, vanadium, and zinc (Kiilsgaard and Van Noy, 1984). The mineralized areas are in the Bayhorse district and in the drainages of Thompson Creek, Slate Creek, Big and Little Boulder Creeks, Fisher Creek, Fourth of July Creek, and Germania Creek (fig. 4).

BASE- AND PRECIOUS-METAL VEIN DEPOSITS

Mining started in the late 19th century with development of many small, high-grade lead-silver vein deposits. The largest are the Skylark and Ramshorn mines in the Bayhorse district and the Livingston mine in Jim Creek, a tributary to Big Boulder Creek. The most favorable host formations for these vein deposits are the black, carbonaceous argillite and limestone of the

Ramshorn Slate of Cambrian(?)-Ordovician age and the Salmon River assemblage of Paleozoic age. All of the vein deposits lie within 4 mi of Cretaceous granitic plutons.

Copper-lead-silver replacement veins with siderite gangue are present in the Bayhorse district, in the black shales of both the Ramshorn Slate and the Garden Creek Phyllite. The Ramshorn and Skylark mines are two formerly productive mines that are present in shear zones in the Ramshorn Slate. These deposits contain tetrahedrite and galena as the principal ore minerals in a siderite gangue. Other sulfide minerals present are sphalerite, chalcopyrite, pyrite, and arsenopyrite. The ore is present in shoots within a shear or lode system. Some shoots were mined 300 to 400 ft both along strike and down dip and ranged in thickness from a few inches to 10 ft (Ross, 1937a). Silver, lead, copper, and small amounts of gold were recovered (Ross, 1937a). The known deposits within the Garden Creek Phyllite are narrow, discontinuous, siderite-quartz-bearing veins that produced small quantities of sphalerite, argentiferous galena, chalcopyrite, and tetrahedrite. The base- and precious-metal vein deposits in the carbonate and quartzite sequences interbedded in the black shales in the Bayhorse district have a different mineralogy than those in the Ramshorn Slate but are considered to have formed at the same time and to have the same origin. They include the Beardsley, Pacific, Riverview, Last Chance, and Red Bird mines (pl. 1). Ore minerals are principally galena and sphalerite in quartz-barite-calcite-fluorite gangue. Lesser amounts of pyrite, tetrahedrite, and chalcopyrite are present (Ross, 1937a). Different chemical and physical properties of the host rock probably account for differences in mineralogy of hypogene ores between the siderite lodes and the quartz-calcite gangue lodes.

The black shale belt that is underlain by the Salmon River assemblage (part of the White Cloud Peaks sub-terrane) contains lead-silver-zinc veins with byproduct tin, antimony, and locally, gold. The Livingston mine (fig. 4) has been the most productive, but many smaller deposits have been productive or have been explored extensively. Small, high-grade shoots contain principally jamesonite, galena, pyrite, and sphalerite but also may contain tetrahedrite, stannite, cassiterite, a silver telluride mineral (hessite?), and arsenopyrite; gangue minerals are quartz, calcite, and jasperoid. Jamesonite-bearing veins with silver, antimony, and small amounts of tin are present in the deposits in the Silver Rule Creek area ($44^{o}11'$ N., $14^{o}35'$ W.), Strawberry Basin ($44^{o}04'$ N. $114^{o}39'$ W.), the Fourth of July Creek area ($44^{o}03'$ N., $114^{o}39'$ W.), at the Livingston mine, and at the Crater mine at the head of Livingston Creek. They are unique to the deposits in the Salmon River assemblage. Lead-silver vein deposits with tin and antimony extend south of the Challis quadrangle in the Wood River Formation and include the Pole Creek area, the Galena district, and Boulder Basin. Galena and sphalerite are the principal ore minerals, silver is present in tetrahedrite, and tin is present as stannite and as small grains of secondary cassiterite. The galena contains considerable antimony and lesser arsenic. Jamesonite is present in minor quantities or not at all. The region with anomalous tin extends for a distance of approximately 30 mi in a north-south direction from Boulder Basin on the south to the Livingston-Silver Rule mine areas. Vein deposits that contain tin also always contain antimony in tetrahedrite and in solid solution in the galena, have high silver values, and, in Boulder Basin, contain significant gold.

The base- and precious-metal vein deposits that are present in the black shale terrane are localized close to contacts with granitic stocks of Cretaceous age or Eocene felsic stocks and dikes, and are under regional thrust faults (Hall and others, 1978). Fluid-inclusion and stable-isotope studies of these deposits show that the hydrothermal fluid that deposited ore in the Wood River area was mainly of meteoric origin, and that the sulfur and lead had a shallow, crustal source. This environment permitted the formation of a hot meteoric water convective system that dissolved metals and sulfur from disseminated or bedded ore minerals in the host Paleozoic black shale and deposited ore in structural traps or favorable beds below the thrust faults.

Ore from the Livingston mine has come from the Livingston vein, which is a stratiform deposit containing predominantly sphalerite but also pyrite, pyrrhotite, arsenopyrite, and silver-bearing galena. There has not been great interest in the past for the sphalerite-rich stratiform ore, and the extent of this stratiform vein is not known. The mine was developed for smaller, high-grade ore bodies of galena, jamesonite, sphalerite, and tetrahedrite that occur at the intersections of large felsic dikes with the Livingston vein (Kiilsgaard, 1949). Figure 5a is a photograph of stratiform zinc ore from the Livingston vein from the border of the Christmas stope. The ore is very fine grained, bedded sphalerite and lesser pyrite and galena. Figure 5b is a photograph of a specimen of ore 25 ft horizontally into the stope near the contact with the felsic 40- to 60-ft-thick Scotch dike. Galena, jamesonite, and pyrite are starting to recrystallize into blebs as much as 0.2 to 1 mm in diameter and to form veinlets that cut across bedding. Figure 5c is a photograph of remobilized ore from the center of the stope. The argillite host rock was shattered at the intersection of the felsic dike and the Livingston vein, and the shattered host rock has bedded sphalerite that has not been remobilized. The matrix between the argillite clasts is filled with remobilized galena and jamesonite, and this ore contains substantial silver. It is apparent that the high-grade lead-silver-antimony ore remobilized as lead-silver sulfantimonide complexes.

MISCELLANEOUS VEIN DEPOSITS

The Aztec mine, located at the head of Pigtail Creek (44°05′ N., 114°44′ W.), a tributary to the Meadows on Warm Springs Creek, is on a shear zone in biotite granodiorite and aplite near the contact with the Grand Prize Formation (fig. 4). It was developed for gold, but also has produced some lead and silver (Ross, 1937a). In the northwest corner of the Livingston Creek 7 1/2-minute quadrangle (pl. 1) a small pit exposes a coarsely crystalline vein of barite, but production from it has been minimal.

STRATABOUND (SYNGENETIC) DEPOSITS

Stratabound deposits of barite, vanadium, and zinc are known to be present in the Salmon River assemblage in the Slate Creek-Mill Creek area. Fisher and May (1983), in a geochemical study of the concentrations and distribution of metals in the Salmon River assemblage, found that the elements most consistently enriched include silver, barium, copper, molybdenum, vanadium, and zinc. Figure 6 shows the range in concentration of anomalous metals in the Salmon River assemblage, the value of anomalously high concentrations as selected from histograms published by Vine and Tourtelot (1970), and the percent of samples with anomalously high concentrations. The analyses show that highly carbonaceous bands in the Salmon River assemblage contained as much as 10,000 ppm vanadium; the assemblage may be of interest as a future resource for vanadium.

This figure is not available in the open-file version of this manuscript.

Figure 5. Ore from Livingston vein. A. Stratiform zinc ore. B. Partly recrystallized zinc ore. C. Remobilized ore from the center of the Christmas stope.

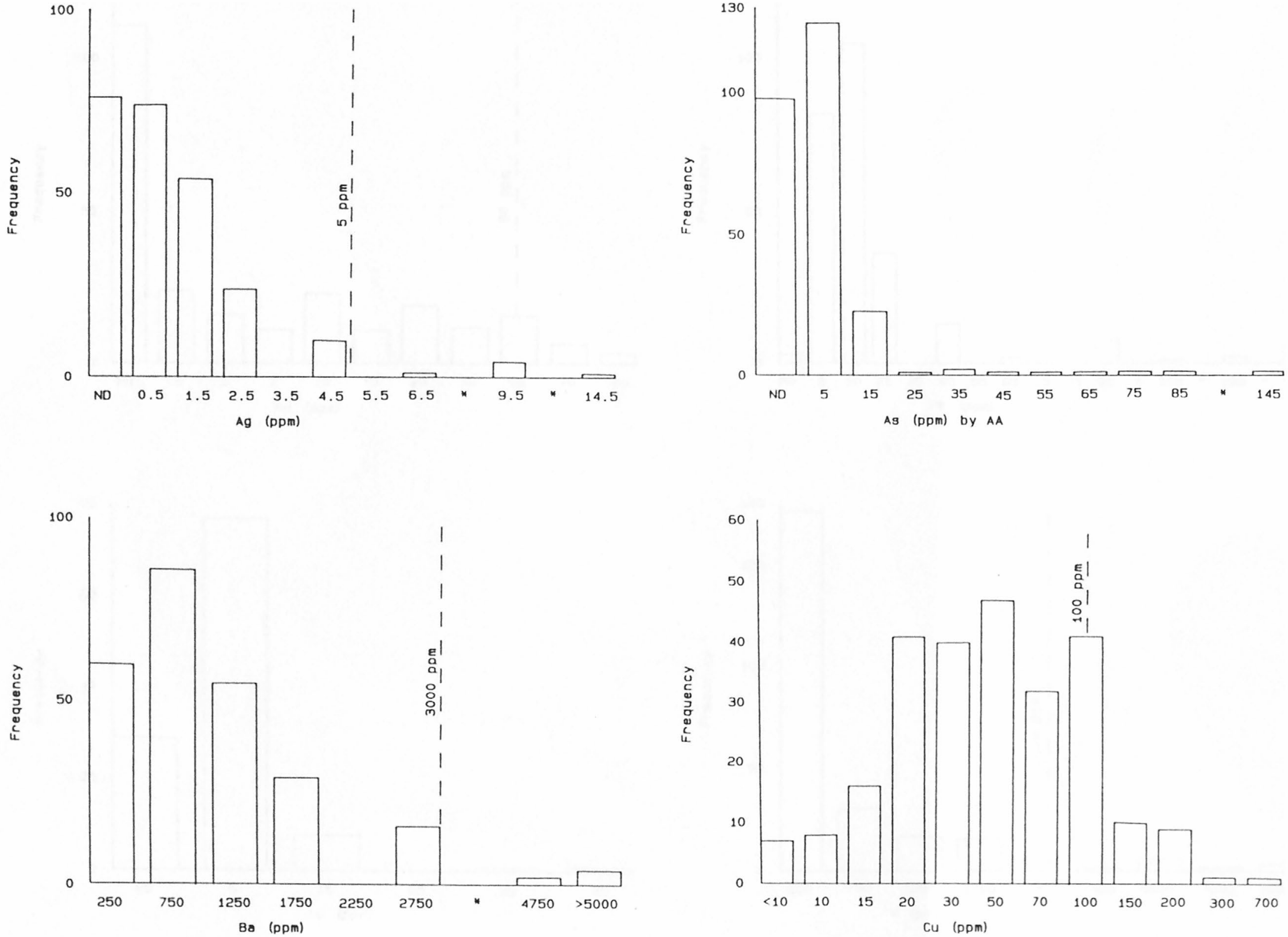

Figure 6. Frequency distribution of elements in anomalous concentrations from 257 samples of Salmon River assemblage. Data from Fisher and May (1983). Dashed lines show threshold values, based on average black shales reported by Vine and Tourtelot (1970). ND=not detected, *=scale change.

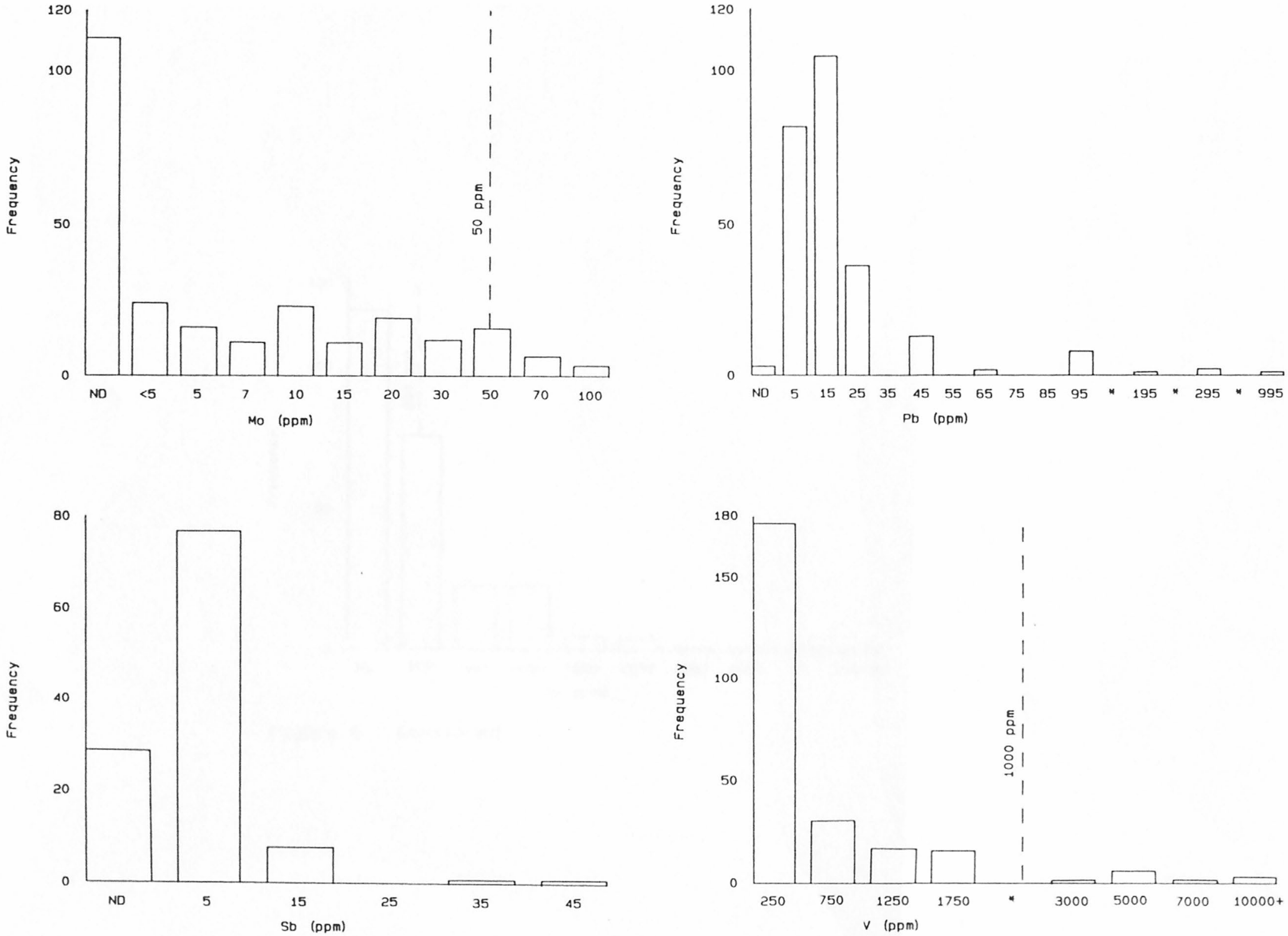

Figure 6. Continued

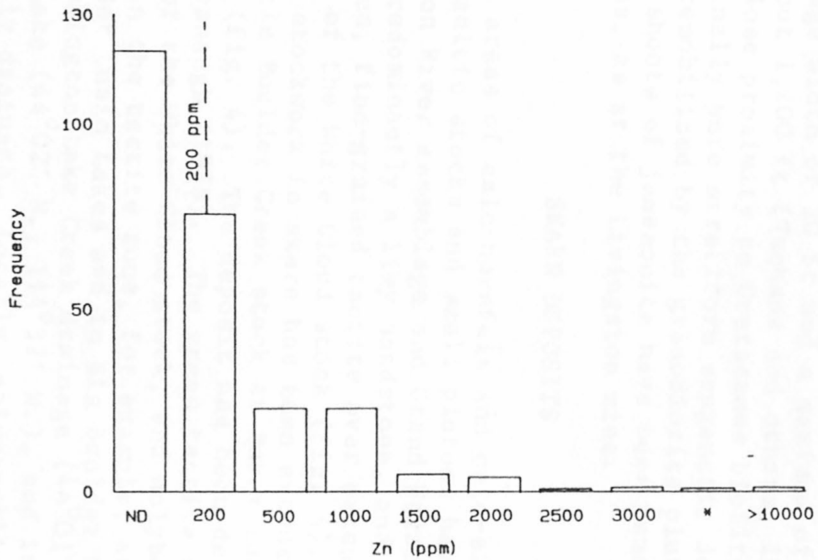

Figure 6. Continued

Zinc is concentrated in the Salmon River assemblage in a belt 10 mi long and 3 mi wide that strikes N. 10° E. in the Slate Creek-Mill Creek area (fig. 4) (Tschanz and others, 1974). Stream-sediment samples collected within this belt contained 100 to 3,000 ppm zinc; samples outside the belt contained less than 500 ppm zinc. This belt is postulated to have been downdropped at the time of sedimentation and to have concentrated zinc-rich hydrothermal brines from which were deposited sphalerite and some galena and pyrite. The Hoodoo mine in this belt contains a stratabound zinc orebody that was drilled under the DMEA program in 1952 (Kiilsgaard, written commun., 1983). Ore reserves inferred from the DMEA work are 870,000 tons that contain 11.0 percent zinc, 0.47 percent lead, and 0.35 oz silver, and have a zinc-cadmium ratio of 1:108 (Tschanz and others, 1974).

In Washington Basin (44°01′ N., 114°39′ W.), one northwest-trending and four large northeast-trending quartz-rich stratabound veins that contain disseminated iron sulfides, sphalerite, scheelite, and some gold were developed in the late 19th century for their gold values. The Empire vein (pl. 1) has an average width of 30 ft and a maximum of 72 ft; it can be traced along strike for about 1,200 ft (Tschanz and others, 1974). These veins are adjacent to or in close proximity to Cretaceous biotite granodiorite plutons. They originally were stratiform syngenetic deposits but have been recrystallized and remobilized by the granodiorite plutons. Locally blebs, veinlets, and small shoots of jamesonite have been remobilized from the syngenetic ore bodies, as at the Livingston mine.

SKARN DEPOSITS

Skarn and large areas of calc-hornfels and calc-silicate rock are widely distributed where granitic stocks and small plutons have intruded limy sections of the Salmon River assemblage and Grand Prize Formation. The Wood River Formation is predominantly a limy sandstone, and it has been metamorphosed to green, fine-grained tactite over extensive areas along the east and south sides of the White Cloud stock (fig. 4). A large molybdenum- and tungsten-bearing stockwork in skarn has been extensively explored on the east side of the Little Boulder Creek stock at Baker Lake near the head of Little Boulder Creek (fig. 4). The deposit has been described by Kirkemo and others (1965) and Cavanaugh (1979). The green tactite zone continues north along the east side of the White Cloud stock, and molybdenite and scheelite are present locally in the tactite zone, for example, at the Baker prospect at the east end of Boulder Chain Lakes and in Big Boulder Basin. Tactite is widespread in the Washington Lake Creek drainage (44°01′ N., 114°37′ W.), south of Washington Lake (44°02′ N., 114°37′ W.), and in Washington Basin north to Fourth of July drainage. Locally, polymetallic skarn minerals are present.

A scheelite-molybdenite skarn deposit occurs at the Tungsten Jim mine in the Thompson Creek drainage. The deposit, which lies 2 mi northwest of the Thompson Creek molybdenite deposit (pl. 1), is on the contact between biotite-granodiorite and tactite near the fault contact between the Grand Prize Formation and the Salmon River assemblage.

IDAHO BATHOLITH TERRANE

By Thor H. Kiilsgaard and Earl H. Bennett,
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INTRODUCTION

The western part of the Challis quadrangle is underlain chiefly by granitic rocks of the Idaho batholith of Cretaceous age (figs. 1 and 7). Intruding the batholithic rocks are a multitude of Tertiary dikes of varying composition and some Eocene plutonic bodies, a few of which are of considerable size. Small roof pendants of metamorphosed sedimentary rocks of uncertain Precambrian-Paleozoic age are exposed sporadically across the batholith, mostly near the eastern side. Our geologic mapping and modal analyses indicate the batholithic rocks may be classified in six different types: tonalite, hornblende-biotite granodiorite, porphyritic granodiorite, biotite granodiorite, muscovite-biotite granite, and leucocratic granite (Kiilsgaard and Lewis, 1985). Batholithic rocks exposed in a small area east of Yellow Pine, in the northwestern part of the quadrangle, were not subdivided as separate types and are shown as mixed rocks on the geologic map (Fisher and others, in press). Also, rocks in the northern part of the Sawtooth Range, west of Stanley, were mapped in 1967-68 and not restudied and are shown on the geologic map (Fisher and others, in press) as Idaho batholith (Ki), but probably are chiefly biotite granodiorite. The massive core of the Idaho batholith is in sharp contrast to other major batholith provinces in the western Cordillera that are composed of more or less individually zoned plutons (Bateman and others, 1963; Mathews, 1958).

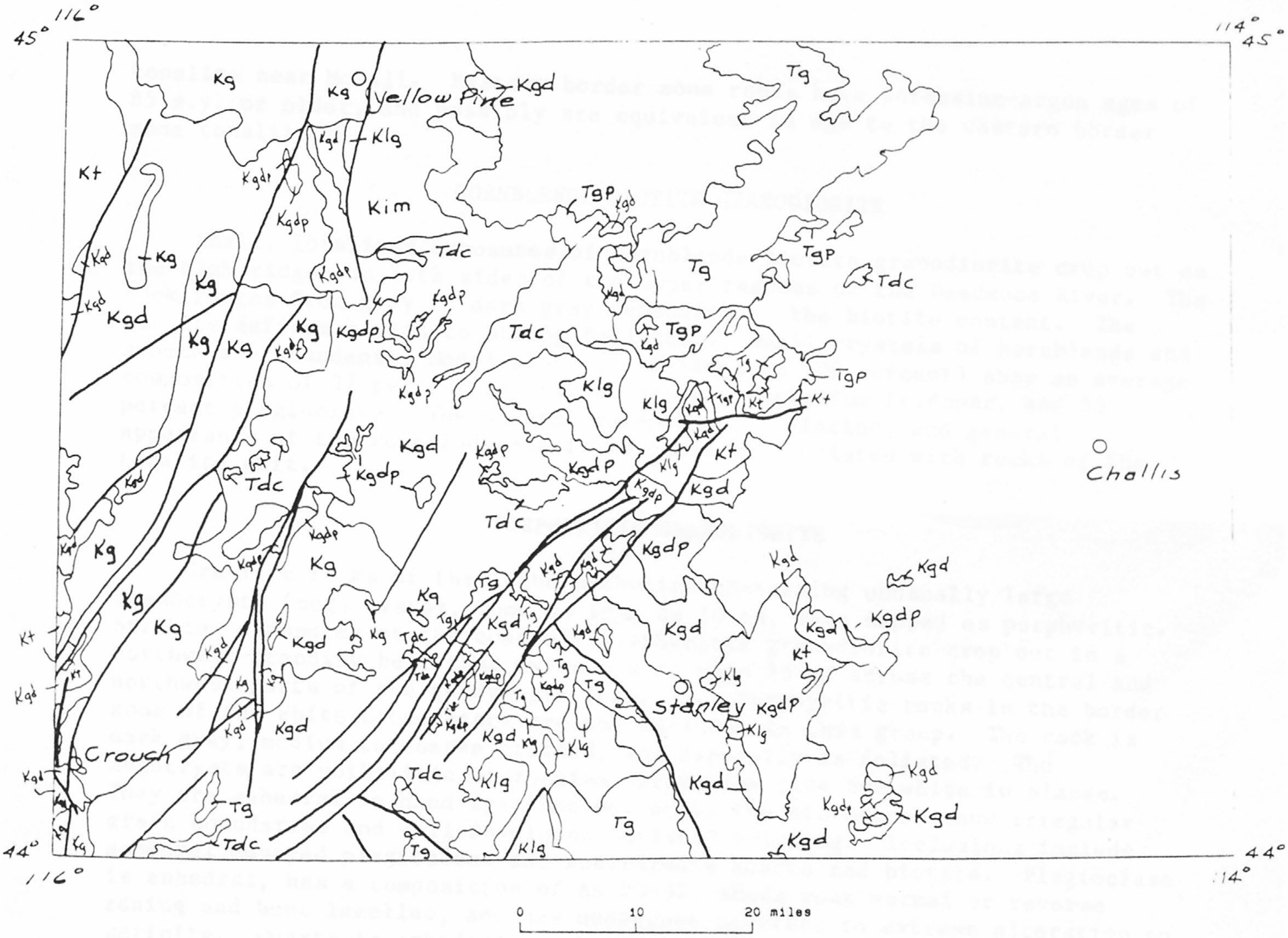
LITHOLOGY OF BATHOLITHIC ROCKS

TONALITE

Tonalite grading to granodiorite is exposed along the western and eastern edges of the batholith. The rock is gray to dark gray, medium to coarse grained, and equigranular to porphyritic. Andesine is the predominant mineral in the rock. As much as 20 percent biotite gives the rock a dark color and defines a foliation that varies from faint at some localities to intense at others. Variable quantities of hornblende occur in the rock, and yellow-brown sphene in crystals as long as 20 mm is common. Apatite, magnetite, allanite, and zircon are the principal accessory minerals. Modal plots of the felsic minerals, using the method of Streckeisen (1973), show a mean composition of 30 percent quartz, 6 percent potassium feldspar, and 64 percent plagioclase.

The quartz diorite gneiss of Donnelly (Schmidt, 1964) is included in the tonalite unit, as are other exposures of quartz diorite and gneissic quartz diorite near the western border of the batholith (Anderson, 1934, 1942, 1951, 1952; Moore, 1959; Ross, 1963; and Taubeneck, 1971). Bodies of hornblende-biotite tonalite also crop out along the eastern border of the batholith, east of Stanley. The eastern tonalite is mixed with biotite granodiorite and other intrusive units, including the Pat Hughes stock and the White Cloud stock, which have modes in the granodiorite to granite range.

Field evidence indicates that tonalite is the oldest of the batholithic rocks. Xenoliths of foliated tonalitic rock have been found in younger biotite granodiorite at several localities in the western and north-central parts of the quadrangle. Conversely, younger biotite granodiorite intrudes



Explanation

TERTIARY

Tg	GRANITE--Pink to gray, medium- to coarse-grained granite, characterized by conspicuous perthitic feldspar phenocrysts
Tgp	GRAY PORPHYRY--Mixed gray and green-gray extrusive and intrusive rocks of intermediate composition
Tdc	DIORITE COMPLEX--Gray to dark gray, fine- to medium-grained rocks that range from diorite to granodiorite in composition. Characterized by abundant hornblende, euhedral biotite, and magnetite

CRETACEOUS

Klg	LEUCOCRATIC GRANITE--Light gray to white, fine- to medium-grained granite that has distinctive anhedral texture. Garnet is common as are small irregular flakes of muscovite
Kg	MUSCOVITE-BIOTITE GRANITE--Gray to light gray, medium- to coarse-grained, equigranular to porphyritic rock that contains visible books of muscovite
Kgd	BIOTITE GRANODIORITE--Gray to light gray, medium- to coarse-grained, equigranular to porphyritic granitoid rock. Biotite is principal mafic mineral; hornblende is absent
Kgdp	PORPHYRITIC GRANODIORITE--Gray to light gray, coarsely porphyritic granitoid rock that contains megacrysts of potassium feldspar as much as 10 cm long
Kt	TONALITE--Gray to dark gray, medium- to coarse-grained, massive to foliated granitoid rock. Plagioclase is the principal mineral; hornblende and sphene are common
Kim	MIXED BATHOLITHIC AND OTHER ROCKS--Mainly alaskite and Precambrian metamorphic xenoliths

Contact

Fault

Figure 7. Map showing principal exposures of Cretaceous and Tertiary plutonic rocks in the Challis 1° x 2° quadrangle.

tonalite near McCall. Eastern border zone rocks have potassium-argon ages of 85 m.y. or older, and possibly are equivalent in age to the western border zone tonalite.

HORNBLENDE-BIOTITE GRANODIORITE

Small, localized exposures of hornblende-biotite granodiorite crop out on the high ridges on both sides of the upper reaches of the Deadwood River. The rock ranges from gray to dark gray depending on the biotite content. The biotite defines a weak to strong foliation. Small crystals of hornblende and sphene are abundant. Modal plots (normalized to 100 percent) show an average composition of 27 percent quartz, 20 percent potassium feldspar, and 53 percent plagioclase. The mineral assemblage, foliation, and general appearance of the rock indicate it is closely associated with rocks of the tonalite unit.

PORPHYRITIC GRANODIORITE

Granitic rocks of the Idaho batholith containing unusually large phenocrysts (megacrysts), some as long as 10 cm, were mapped as porphyritic. Striking exposures of the coarsely porphyritic granodiorite crop out in a northwest-trending belt that extends more than 75 mi across the central and northwest parts of the quadrangle (fig. 7). Porphyritic rocks in the border zone of the White Cloud stock are not included in this group. The rock is dark gray, medium to coarse grained, and typically is foliated. The megacrysts are poikilitic microcline, generally pink but white in places. They are euhedral in hand specimen but under the microscope show irregular grain boundaries and well-developed Carlsbad twinning. Inclusions include anhedral embayed plagioclase and subordinate quartz and biotite. Plagioclase is anhedral, has a composition of An 23-37, shows weak normal or reverse zoning and bent lamellae, and has undergone moderate to extreme alteration to sericite. Quartz is anhedral and has well-developed undulatory extinction. The rock contains as much as 15 percent biotite that defines the foliation. Hornblende is common, is as much as 8 mm in maximum dimension, and in rare instances has cores of clinopyroxene. Epidote is present locally, and sphene is a common accessory mineral.

Where foliated, hornblende-bearing porphyritic granodiorite contains many features of the tonalite and hornblende-biotite granodiorite; it differs mainly in containing microcline megacrysts, the distribution of which is so variable that modal estimates of the rock are not consistent.

BIOTITE GRANODIORITE

Biotite granodiorite is the most common rock type of the batholith and is widely exposed (fig. 7). The rock is light gray, medium to coarse grained, and equigranular to porphyritic. Plagioclase (oligoclase) is the chief component of the rock, with lesser quantities of quartz and potassium feldspar. Biotite averages about 5 percent of the rock and is pervasively altered to chlorite. Sericite, altered from feldspar, is widespread throughout the rock, but hornblende and primary muscovite are rarely present. Accessory minerals include minute quantities of sphene, allanite, zircon, monazite, and opaque minerals. Foliation is rare. The rock weathers readily, and most of the surface area is covered by a thick blanket of overburden.

Field relations indicate that most of the biotite granodiorite is younger than tonalite or hornblende-biotite granodiorite. In the western part of the quadrangle, biotite granodiorite intruded older tonalite. Xenoliths of hornblende-biotite granodiorite in biotite granodiorite are exposed on high ridges east and west of the upper reaches of the Deadwood River. Older biotite-hornblende granodiorite is exposed along the eastern border of the batholith.

MUSCOVITE-BIOTITE GRANITE

Muscovite in granitic rocks of the Idaho batholith occurs principally as secondary muscovite formed from alteration of feldspar minerals. Along the western side of the quadrangle, however, there is an irregular, north-trending belt of granite grading to granodiorite that contains notable quantities of primary muscovite. We have mapped this rock as muscovite-biotite (two-mica) granite (fig. 7), using laminated plates or books of muscovite large enough to see in hand specimens as the principal field criterion.

Muscovite-biotite granite is light-gray to white, medium- to coarse-grained, equigranular to porphyritic rock that consists chiefly of oligoclase, quartz, and potassium feldspar. Modal composition varies, but the mean value is within the granite field. Muscovite makes up as much as 5 percent of the rock but probably averages about 2 percent in the specimens that were studied. The biotite content averages less than 5 percent. Other characteristics of the rock are local occurrences of garnet, the absence of hornblende, and the rare occurrence of sphene. The rock is nonfoliated.

Muscovite-biotite granite is transitional with biotite granodiorite through a zone as wide as 1-2 mi or more. At one locality near the western boundary of the quadrangle, the muscovite-biotite granite has an aphanitic texture in a border zone about 23 ft thick at the contact with biotite granodiorite. The texture could have been caused by intrusion into cooler biotite granodiorite. The location of the muscovite-biotite granite in the central part of the batholith and the transitional contact of the rock with biotite granodiorite suggest that muscovite-biotite granite is younger.

LEUCOCRATIC GRANITE

Leucocratic granite is light gray to nearly white, fine to medium grained, and has a distinctive anhedral texture. It consists of roughly equal amounts of quartz, plagioclase, and potassium feldspar. The plagioclase (An 25-30) commonly is altered to sericite as is the potassium feldspar, which is chiefly perthitic microcline. Biotite may constitute as much as 2 percent of the rock and generally is extensively altered to chlorite. Garnets as large as 2 mm in diameter are locally present, as are minute amounts of primary muscovite. Magnetite is a common accessory mineral, but sphene was found only rarely. Hornblende was not found in the rock.

Leucocratic granite occurs as dikes, sill-like masses, and small irregular stocks that are resistant to erosion and tend to form high points on ridges. Exposures of larger masses of the rock in the southwestern part of the quadrangle are in upthrown blocks between regional faults. The extent of the leucocratic granite was not recognized prior to the Challis study, but it may account for twenty percent of the granitic rocks in the batholith.

The leucocratic granite intrudes biotite granodiorite, commonly along joints, which indicates that the biotite granodiorite was solidified prior to intrusion. Leucocratic granite, in turn, is intruded by plutonic rocks of

Eocene age. The relation of the leucocratic granite to muscovite-biotite granite is not clear. The two rock types are comparable mineralogically and chemically; they differ largely in texture and grain size. Leucocratic granite is probably a late stage differentiate of the muscovite-biotite granite and therefore is considered as the "last gasp" of the Cretaceous plutonic event.

Leucocratic granite contrasts sharply with the other plutonic rocks in its method of emplacement. The leucogranite was forcibly injected, and in places contains large stope-blocks of the intruded rock. In contrast, the massive core of biotite granodiorite muscovite-biotite granite appears to have been emplaced much more passively.

APLITE AND PEGMATITE DIKES

Dikes of aplite and pegmatite are the only dikes in the Challis quadrangle that are clearly related to Cretaceous granitic rocks. Small aplite dikes a few centimeters thick are common, particularly along ridge tops in areas considered to be upper zones of the batholithic rocks. Pegmatite dikes are exposed in some areas, and locally are as much as several feet thick.

GEOCHEMICAL COMPOSITION OF BATHOLITHIC ROCKS

Analyses of major-element oxides from samples of the batholithic rocks (table 3) show the more mafic rocks, the tonalite and hornblende-biotite granodiorite, to be low in SiO_2 and K_2O and high in Al_2O_3, Fe_2O_3, MgO, CaO, TiO_2, and P_2O_5, with respect to the more felsic rocks in the central part of the batholith.

AGE RELATION OF BATHOLITHIC ROCKS

The six types of batholithic rocks in the Challis quadrangle may be grouped into three categories, each of which appears to have been emplaced at a different time:

1. A batholithic border facies of foliated tonalite grading to porphyritic hornblende granodiorite and to biotite granodiorite in the central part of the Challis quadrangle.
2. A major central part of the batholith that consists of biotite granodiorite in transitional contact with muscovite-biotite granite. The core location, transitional contact, and potassium-argon ages suggest that the muscovite-biotite granite may be slightly younger.
3. Stocks and dikes of leucocratic granite that intrude older rocks.

Radiometric ages of the rocks are shown in table 4. The range in age of rock types indicates overlapping of emplacement, which may or may not be real. Regional Tertiary hydrothermal alteration has resulted in argon loss in biotite (Criss and Taylor, 1983), the potassium-argon dating of which, in many localities, gives dates that reflect a minimum age rather than the age of emplacement. Three of the leucocratic granite samples were taken from hydrothermally altered zones, and biotite from the samples gave ages ranging from 66 to 64 m.y., ages that may be too young due to argon loss. Biotite from the other three leucocratic granite samples gave ages of about 72 m.y., an age that may be more representative of the emplacement age of the rock. Muscovite-biotite pairs in six samples of muscovite-biotite granite gave concordant ages that average about 72 m.y. Only biotite was dated in the 10

Table 3.--Mean values of major-element oxides of Cretaceous and Eocene plutonic rocks in the Challis quadrangle

[Analytical determination by X-ray fluorescence. Analysts: J.E. Taggart, J.S. Wahlberg, A.J. Bartel, J.D. Baker, L.L. Jackson, G.R. Mason, D.B. Hatfield, F.E. Lichte, and H.G. Neiman, U.S. Geological Survey; J. Amistoso, F.J. Moye, S.T. Luthy, and W.B. Strowd, Washington State University Laboratory]

Rock type	No. of samples	SiO_2	Al_2O_3	[1]Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO
		(wt. percent)									
Cretaceous											
Leucocratic granite	11	75.3	14.0	0.73	0.1	0.78	4.3	4.11	0.05	0.05	0.02
Muscovite-biotite granite	12	73.8	14.6	.92	.3	1.41	3.8	3.47	.10	.04	.03
Biotite granodiorite	22	71.9	15.2	1.55	.4	1.91	4.1	3.30	.21	.07	.03
Hornblende-biotite granodiorite	3	66.5	15.5	3.79	1.7	3.98	3.3	2.97	.63	.21	.07
Tonalite	11	64.0	16.9	4.40	1.6	4.64	3.7	2.36	.77	.26	.07
Eocene											
Pink granite	20	75.6	13.1	1.19	0.2	0.58	3.3	4.87	0.11	0.05	0.02
Diorite complex	25	62.9	16.5	4.83	2.2	4.44	3.5	3.22	.74	.26	.08

[1]Total iron reported as Fe_2O_3.

Table 4.--Potassium-argon ages of Cretaceous and Tertiary plutonic rocks in or bordering the Challis quadrangle

[Dated by R.J. Fleck and R.F. Marvin, U.S. Geological Survey, and R.L. Armstrong (1976)]

Rock type	No. of samples	Range in age
	Cretaceous	
Leucocratic granite	6	72-64 m.y.
Muscovite-biotite granite	8	75-66 m.y.
Biotite granodiorite	10	82-69 m.y.
Tonalite and porphyritic granodiorite	6	73-97 m.y.
	Eocene	
Pink granite	9	44-47 m.y.
Diorite complex	5	46-48 m.y.
Gray porphyry	3	47-50 m.y.

biotite granodiorite samples, and the average age was about 74 m.y. Zircon from a sample of porphyritic granodiorite taken east of Stanley gave a uranium-lead age of 88±6 m.y., an age that agrees with a potassium-argon age of 84.7±2.9 m.y. obtained from hornblende collected at the same locality. Hornblende from quartz diorite collected near Donnelly on the western side of the batholith (west of the Challis quadrangle) gave a potassium-argon age of 90±3 m.y. (Armstrong, 1976). The two hornblende ages suggest the tonalite-porphyritic granodiorite is in the range of about 85-95 m.y. old.

Radiometric dating of the rocks supports geologic mapping evidence, which suggests that the tonalite-porphyritic hornblende granodiorite on the western and eastern sides of the batholith are the oldest plutonic rocks and that leucocratic granite is the youngest.

GENETIC RELATION OF BATHOLITHIC ROCKS TO MINERAL DEPOSITS

The Idaho batholith is host rock for a number of different types of mineral deposits, but most of them do not appear to be genetically related to the batholith. Exceptions are some small polymetallic skarn (tactite) deposits along the eastern margin of the batholith. Typical of these are several tungsten-zinc-lead deposits in or near the headwaters area of Fourth of July Creek. Polymetallic skarn deposits on Copper Mountain southeast of Banner Creek are in small roof pendants of metamorphosed sedimentary rocks at the contact with biotite granodiorite. More productive tungsten skarn deposits include the Springfield scheelite mine and the Tungsten Jim mine (pl. 1). The contact relationship of these skarn deposits with batholithic rocks suggests a batholithic relationship that was noted by Cook (1956), who described a northwest-trending belt of tungsten deposits that is, in part, along the eastern margin of the batholith.

Several molybdenum deposits also along the eastern margin of the Idaho batholith are clearly related to the batholith. These include the deposit at the Thompson Creek molybdenum mine, which is the largest open-pit mine in Idaho and has a mill capacity of 25,000 tons of ore per day, and the Little Boulder Creek deposit in the White Cloud Peaks area (Hall, this volume, p. 152). The Knapp Creek deposit (pl. 1) has characteristics similar to those of the Thompson Creek deposit and is believed to be related to batholithic intrusion.

Pegmatite dikes throughout the batholith are clearly related to it and some of these in the area southeast of Garden Valley have been prospected for columbite and samarskite (Fryklund, 1951). Large crystals of these minerals have been mined from the pegmatites, but there is no record of production of the minerals or of potassium feldspar or muscovite both of which are common constituents of the dikes. Muscovite in the pegmatites was found by L.E. Shaffer (written commun., 1944) to be of non-strategic quality.

Field evidence suggests that several base- and precious-metal veins in the batholith may be related to it. These include the Deadwood, Argentite, Merry Blue and Merry Jane deposits in the vicinity of the Deadwood River, and the Eureka Silver King deposit on the South Fork of the Salmon River (pl. 1). In the eastern part of the batholith, the Lost Packer mine in the Loon Creek area, the Greyhound and Seafoam mines in the Seafoam mining district (Ross, 1936), and a few other small vein deposits in that region may be related genetically to intrusion of leucocratic granite, as may a northwest-trending belt of low-grade geochemical anomalies, the location of which coincides with the northwest-trending belt of porphyritic granodiorite and some leucocratic dikes and stocks (Fisher and others, in press).

Radioactive black-sand deposits in the western part of the quadrangle were derived from erosion of the batholith.

CHALLIS VOLCANIC ROCK TERRANE

By Frederick S. Fisher and Kathleen M. Johnson

INTRODUCTION

The Challis volcanic rock terrane covers large areas of the northern and eastern parts of the quadrangle (pl. 2; fig. 1). It overlaps the trans-Challis fault system terrane (Kiilsgaard and Fisher, this volume, p. 62; pl. 2) and surrounds parts of the Tertiary intrusive rock terrane (Kiilsgaard and Bennett, this volume, p. 54; pl. 2). The volcanic terrane includes Tertiary extrusive volcanic rocks and volcaniclastic sediments both within and outside of large calderas, on the sides of stratovolcanoes, and in the vicinity of numerous small vents. Volcanic rocks include lavas, flow breccias, and an assortment of pyroclastic rocks including tuffs and tuff-breccias. Volcaniclastic sediments include a wide variety of water-laid tuffs, mudflows, caldera-wall slump breccias, intracaldera lake bed sandstones and siltstones, and debris-avalanche deposits. Small areas of nonvolcanic sediments are included in the Custer graben and in the southeastern part of the quadrangle. The terrane also includes a great diversity of hypabyssal dikes, sills, plugs, domes, and irregular stocks. The large Tertiary intrusive bodies, including the Casto pluton (44°48′ N., 114°49′ W.) and the Sawtooth batholith (44°08′ N., 115°01′ W.), are described in the Tertiary plutonic terrane.

DISTRIBUTION AND CHARACTER

Within the Challis quadrangle, the Challis Volcanic Group is a suite of calc-alkaline, peraluminous volcanic rocks erupted during Eocene time (Ekren, 1985; Fisher and others, in press). Potassium-argon ages indicate that the bulk of the suite ranges in age from about 51 m.y. to about 45 m.y. Locally, minor activity persisted to about 39 m.y. Rock compositions range from magnesium-rich basalt to alkali rhyolite, with volumetric predominance of intermediate compositions, such as dacite and rhyodacite. Volcanic eruptions in the quadrangle were of two kinds: relatively quiescent eruptions of intermediate and mafic lavas forming stratovolcanoes and dome complexes, and violently explosive ash-flow tuff eruptions associated with the formation of cauldron complexes. Volcanic activity began with eruption of intermediate and mafic lavas from numerous vents; those preserved are chiefly in the southeastern part of the quadrangle. Most of this activity had ceased by about 49 m.y. Cauldron formation began at about this time with development of the Corral Creek cauldron segment (fig. 1) in the northeast part of the quadrangle.

Voluminous ash-flow eruptions and major cauldron collapse began about 48.4 m.y. with the eruption of the rhyodacitic tuff of Ellis Creek (this unit, as well as all others named in this chapter, is fully described in Fisher and others, in press). Initial subsidence of most of the Van Horn Peak cauldron complex (fig. 1) was associated with this mammoth eruption. Subsequent events that affected parts of the cauldron complex were: eruption of quartz latitic tuff (tuff of Eightmile Creek) at about 47.5 m.y., triggering subsidence of the Custer graben; accumulation of a thick sequence of rhyodacitic to quartz latitic tuff (tuff of Camas Creek-Black Mountain) within the cauldron complex; and subsidence of the Panther Creek graben. The final events in the formation of the cauldron complex were eruptions of alkali rhyolitic ash-flow tuffs. The Twin Peaks caldera (fig. 1) was formed by eruptions of this type between about 46.5 m.y. and 45 m.y. The alkali rhyolitic tuffs in the Castle Rock cauldron segment (fig. 1) are about this age or somewhat older.

A roughly parallel sequence of events took place in the Thunder Mountain cauldron complex (fig. 1), beginning around 48 m.y.-47 m.y. Rhyodacitic ash-flow tuff (dime- and quarter-size lapilli tuff) is the oldest voluminous pyroclastic rock exposed. Subsequent eruptions at about 46 m.y. produced alkali rhyolitic ash-flow tuff (Sunnyside rhyolite tuff). Fine-grained lacustrine sediments and intercalated landslide debris and talus (Dewey beds) were deposited after subsidence following these youngest eruptions.

Challis volcanism was accompanied by emplacement of stocks and plutons that range in composition from diorite to granite, and by intrusion of swarms of dikes that range in composition from diabase to rhyolite. The most mafic plutons and the dike swarms are exposed in the western part of the quadrangle, in the uplifted and deeply eroded terrane underlain by the Cretaceous Idaho batholith. Much of this area presumably once was covered by Tertiary volcanic rocks. The dioritic and granodioritic plutons are as old as about 47 m.y. The granite ranges in age from about 47 m.y. to about 44 m.y.; many samples are dated at about 45 m.y. The granitic Casto pluton (Kiilsgaard and Bennett, this volume, p. 54) was emplaced within the Van Horn Peak cauldron complex adjacent to the Thunder Mountain cauldron complex. The Sunnyside rhyolite tuff and the tuff of Challis Creek are extrusive counterparts of the alkali granite of the Casto pluton.

Extrusive rocks within the volcanic terrane are mostly flat lying to gently dipping. Near caldera boundaries some beds are steeply dipping as a result of slumping of caldera walls, as in the Twin Peaks caldera (Hardyman, 1985). Steep dips are also present locally as a result of high-angle faulting. Nearly vertical primary dips are present in pyroclastic rocks close to the Van Horn Peak volcanic vent (Ekren, 1985). Regionally, the older volcanic rocks were uplifted by the emplacement of the Casto pluton and dip away from the pluton to the southeast and northwest (Fisher and others, in press).

Many features associated with Challis volcanism and intrusive activity are localized along the trans-Challis fault system (Kiilsgaard and Fisher, this volume, p. 62). Northeast-trending faults of the system outline the Custer graben, Knapp Creek graben, and the Panther Creek graben and appear to control the shape of the Twin Peaks caldera (fig. 1). The Van Horn Peak cauldron complex straddles the trans-Challis fault system.

HYDROTHERMAL ALTERATION

Hydrothermally altered rocks are common in the volcanic terrane. Criss and others (1984) described a large area of ^{18}O depletion in volcanic rocks surrounding the Casto pluton (44°48′ N., 114°49′ W.). Rocks close to the Casto pluton and deep in the volcanic pile have low ^{18}O contents and increased calcite, chlorite, and epidote. In the Twin Peaks caldera, zeolite minerals are developed along fracture systems thousands of meters long (Hardyman, 1985). Elsewhere in the volcanic terrane extensive areas of hydrothermally altered rocks are present in all mining districts. Altered rocks associated with ore deposits are commonly highly silicified, bleached, and stained with iron oxides. They contain variable amounts of sericite, chlorite, clay minerals, fluorite, secondary silica, arsenopyrite, and pyrite. Silicified zones several kilometers long and tens to hundreds of meters wide are present in the Thunder Mountain cauldron complex (Leonard and Marvin, 1982). In the Custer graben, two zones of altered rocks thousands of meters long by tens to hundreds of meters wide have been subjected to silicification, sericitization, propylitization, and advanced argillic alteration (McIntyre and Johnson, 1985). Altered rocks are also present along many of the faults in the volcanic terrane, especially caldera-bounding structures such as faults along the southeastern margin of the Panther Creek graben and ring faults of the Twin Peaks caldera.

MINING ACTIVITY

Commodities produced from the Challis volcanic terrane include gold, silver, copper, lead, zinc, fluorspar, uranium, and building stone. Base- and precious-metal mines are concentrated in the Thunder Mountain, Gravel Range, Parker Mountain, and Yankee Fork mining districts (pl. 1). Parts of the Big Creek and Stanley districts are also in the volcanic terrane, and the Yellow Pine, Bayhorse, and Loon Creek districts are contiguous to it. Prospectors were active in the late 1860′s and early 1870′s; most of the districts saw their greatest precious and base metal production between 1880 and 1920. Some of the largest early producers were the General Custer, Bismark, and Montana mines in the Yankee Fork district and the Dewey mine in the Thunder Mountain district. Notable producers from the mid 1920′s to 1942 were the Sunnyside mine in the Thunder Mountain district and the Lucky Boy mine in the Yankee Fork district (pl. 1). Output from many mines that have produced a few hundred ounces of gold and over 1,000 oz of silver have waxed and waned since the late 1800′s; prospecting and development work continues to the present. Gold and silver have been the major metals of interest with incidental production of base metals. Fluorspar was produced from mines near Meyers Cove sporadically between 1951 and 1970. Uranium ore production totaled 7,000 tons at 0.18 percent U_3O_8 between 1958 and 1960. Near the town of Challis the tuff of Penal Gulch has been quarried for building stone.

ORE DEPOSITS

Precious-metal veins occur in all of the mining districts in the volcanic terrane but are best developed in the Yankee Fork district. The veins formed at shallow depths and ore occurs along the structures in rich bonanza shoots. Silver is more abundant than gold, commonly in ratios of 80 or 90 to 1. Base metals are not abundant in the veins, and only a few mines have recorded byproduct production of copper, lead, or zinc. Where present, the base metals are generally in chalcopyrite, covellite, galena, and sphalerite. Most of the gold occurs as free gold or as electrum.

Fluorite is a common gangue mineral in precious metal veins, and ore grade fluorite has been produced from veins in the Meyers Cove district. The fluorite occurs as crustified bands with chalcedony in composite open-space filling veins. In most places the veins are aggregates of small fracture zones. The richest fluorspar ore occurs in lenticular shoots several feet wide by several hundred feet long. The shoots are scattered along northeast-striking fissure and fracture zones several hundred to a few thousand feet in strike length.

Stockwork deposits of precious metals occur in the Gravel Range, Parker Mountain, and Yankee Fork districts. These deposits are associated with small high-level rhyolite domes and dikes, the locations of which are controlled by structures associated with the trans-Challis fault system (Kiilsgaard and Fisher, this volume, p. 62). Historic production from these deposits has been small, several hundred ounces at most; however, they may contain significant resources of gold and silver in low-grade, large-tonnage deposits.

Stratabound precious metal deposits in the Thunder Mountain caldera are some of the largest producers of gold and silver in the volcanic terrane. These ore bodies are of two types: deposits in epiclastic sediments, as at the Dewey mine, and deposits in intracaldera tuffs, as at the Sunnyside mine. At the Dewey mine, gold and silver occur as free gold and electrum in cracks and seams in dark carbonaceous mudflows, conglomerates, and sandstones. At the Sunnyside mine, gold and silver in a gangue of quartz, clay, sericite, and pyrite are present along fractures in a blanket-like altered zone in the Sunnyside tuff.

Uranium occurs in arkosic sediments at the base of the Tertiary section in the Custer graben. The uranium is found in carbonaceous horizons erratically distributed both horizontally and vertically along a zone as much as 6 mi long and 40 ft thick (Choate, 1962). Uranium minerals are uraninite and coffinite; pyrite and marcasite are also present.

Irregular replacement deposits of zeolite minerals occur along medial faults of the Twin Peaks caldera (Hardyman, 1985). The zone of zeolitized rock is approximately 7.5 mi long by 0.75 mi wide. In this zone, zeolite minerals replace glass shards and pumice fragments in altered ash-flow tuff.

Volcanic and plutonic activity associated with the development of the Challis volcanic field had a profound influence on the distribution and type of ore deposits found in the volcanic terrane. Large-scale hydrothermal systems were established around the Casto pluton during its emplacement (Criss and others, 1984), and more localized hydrothermal systems caused mineralization and alteration around many smaller domes, dikes, irregular plugs, and stocks (McIntyre and Johnson, 1985). The movement of the hydrothermal fluids was controlled by faults, fracture zones, and joints associated with the trans-Challis fault system and with the development of the caldera complexes. Fluid movement was also controlled by the location of permeable rock units both inside and outside of caldera complexes. Tertiary hydrothermal fluids remobilized base and precious metals from Precambrian, Paleozoic, and Cretaceous rocks and redeposited the metals in the vein, stockwork, stratabound, and replacement deposits found in the volcanic terrane. In addition to remobilizing many metals, the Tertiary igneous activity also introduced beryllium, uranium, thorium, molybdenum, tin, gold, silver, mercury, antimony, and fluorine to the rocks of the area (Bennett, 1980; Fisher, 1985).

EOCENE PLUTONIC ROCK TERRANE

By Thor H. Kiilsgaard and Earl H. Bennett,
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INTRODUCTION

Eocene plutonic rocks in the Challis quadrangle are part of a diorite-granite bimodal group. The two types are mineralogically and chemically distinct. Each plutonic type has associated hypabyssal intrusive rocks that collectively form swarms of dikes that are common in the area. Dacite and rhyodacite dikes are equivalent to rocks of the diorite complex and rhyolite dikes to granite. Most of the dikes in the western part of the quadrangle belong to these two groups. Based on the distribution and similarity of rock types, each group of hypabyssal dikes probably is equivalent to volcanic rock units that are part of the Challis volcanic field. Both rock types of the bimodal plutonic group are about equal in areal extent; the granite plutons are larger and the diorite exposures smaller but more numerous. The plutonic rocks have characteristics of anorogenic (A-type) granites and probably are genetically related to intracontinental rifting or extension (Bennett and Knowles, 1985).

LITHOLOGY

DIORITE COMPLEX

A suite of rocks collectively called the diorite complex occurs in the Challis quadrangle (fig. 7). These rocks range in composition from nonporphyritic diorite to porphyritic granodiorite, with quartz monzodiorite grading to porphyritic granodiorite most prevalent. Porphyritic units often contain fine-grained equivalents as a chilled-border facies. The rocks are characterized by abundant hornblende, euhedral biotite, magnetite, and complexly zoned plagioclase (Lewis, 1984), and they weather to a distinctive chocolate brown soil that is darker than soil formed from other granitic rocks in the area. The diorite rocks are chemically distinct from the granitic rocks and also from the younger phases of the Cretaceous Idaho batholith. They are similar to the tonalites that are the oldest phases of the batholith.

Dioritic rocks of Tertiary age were first recognized in the northeast part of the Challis quadrangle by Ross (1934b). Similar rocks in the Boise Basin (44°00′ N., 115°55′ W.) and along the south-central border of the quadrangle were described by Anderson (1947) and Kiilsgaard (1983a). Other exposures include those at Monumental Peak, Lake Mountain, Pinyon Peak, Red Mountain, and in the vicinity of Rapid River (pl. 1; Fisher and others, in press). Of these occurrences, the largest exposure is along Rapid River, where a complex of small diorite stocks and swarms of associated fine-grained, gray to green, nonporphyritic to porphyritic dacite to rhyodacite dikes are exposed along the canyon walls. The tuff of Ellis Creek, tuff of Eightmile Creek, and tuffs of Camas Creek and Black Mountain (Fisher and others, in press) may be related to the diorite complex and its hypabyssal equivalents (Bennett and Knowles, 1985).

GRAY PORPHYRY

A sequence of mixed gray and green-gray extrusive and intrusive rocks of intermediate composition is widely exposed east of Rapid River and northwest of the Middle Fork Salmon River (Fisher and others, in press). At Rapid River, near the mouth of Sheep Creek (44°39′ N., 115°03′ W.), gray porphyry is in contact with rock of the diorite complex, and both are likely related. The two rock types have comparable mineral composition, color, appearance, and radiometric ages (table 4).

GRANITE

Eocene granite is distinguished by coarse granitoid texture and abundant perthitic potassium feldspar, which gives the rock its characteristic pink color. In addition to color and texture, the rock contains miarolitic cavities indicative of shallow epizonal emplacement. The cavities contain crystals of microcline, smoky quartz, beryl, topaz, and fluorite. Tertiary granite has an average uranium, thorium, and potassium-40 content that is two to three times higher than granitic rocks of the Cretaceous Idaho batholith as measured by gamma ray spectrometry. The radioactivity causes the smoky color in quartz crystals.

Many spectacular peaks in Idaho are in Tertiary granite. Steep jointing tends to produce sharp spires and steep topography. This is in contrast to the Cretaceous batholith that has a more subdued topographic expression and concordant elevations.

An average felsic composition of the granite contains 31 percent quartz, 37 percent potassium feldspar, and 31 percent plagioclase. Biotite is present in quantities ranging from two to five percent, and hornblende occurs sparingly. Sphene, allanite, monazite, zircon, apatite, and magnetite are accessory minerals.

Eocene dioritic and granitic rocks differ in chemical content (table 3). Pink granite tends to be similar chemically to the felsic Cretaceous plutonic rocks; however, the range in silica content in the Tertiary granite is much less than in the Cretaceous granitic rocks. The Eocene granites also generally have less aluminum, magnesium, and calcium and more potassium. Eocene granite contains more rubidium and less strontium than do the Cretaceous plutonic rocks (table 5), and has a higher content of the large cation trace elements, including tin, tungsten, thorium, uranium, molybdenum, niobium, zirconium, fluorine, and beryllium. Biotite in the granite tends to be closer to the iron-rich annite member than to the magnesium-rich phlogopite member (Bennett and Knowles, 1985).

TERTIARY DIKES

Countless Tertiary dikes crop out in the Challis quadrangle, some as individual dikes, others as members of large dike swarms. The dikes range from a few inches to hundreds of feet thick and from a few feet to several miles in length. Most strike northeast and dip steeply, but others strike in diverse directions. The dikes may follow faults, but many fill joints in the country rock.

The dikes range from rhyolite to diabase in composition, but light-colored rhyolite-quartz latite and darker gray-green rhyodacite-dacite dikes are most common. Most of the dikes are porphyritic and contain phenocrysts of feldspar and quartz set in an aphanitic groundmass. This is particularly true of the rhyolite-quartz latite dikes. Mafic dikes may contain phenocrysts of biotite and hornblende. The dike rocks are noticeably altered, particularly the rhyolite-quartz latite dikes. Feldspar minerals are altered to sericite, biotite to chlorite, and the quartz phenocrysts are rounded and embayed. Occasionally, pyrite in the dike rocks is oxidized to goethite, which commonly gives rhyolite outcrops a reddish tint.

Rhyolite dikes show a close affinity to Eocene pink granite both spatially and in mineral composition. Rhyolite dikes, like pink granite, are more radioactive than other dikes, and are clustered near exposures of Eocene granite, as in the headwaters area of Eightmile (44°15′ N., 115°23′ W.) and Warm Springs Creeks (44°19′ N., 115°19′ W.) west of Stanley, and along the North Fork of Boise River immediately south of the Challis quadrangle. By contrast, rhyodacite-dacite dikes are compositionally similar to rocks of the diorite complex and tend to cluster near exposures of those plutonic rocks, as

Table 5.--Rubidium-strontium analyses of plutonic rocks, Challis quadrangle

[Analyses by Robert Fleck and B. Hatfield, U.S. Geological Survey]

Rock type	No. of samples	Rubidium	Strontium
		(ppm)	
Cretaceous			
Leucocratic granite	9	86	417
Muscovite-biotite granite	5	104	594
Biotite granodiorite	17	72	626
Tonalite	4	88	639
Eocene			
Pink granite	8	142	193
Diorite complex	11	86	676

in the dike swarm east of Garden Valley along South Fork Payette River and along Rapid River (Fisher and others, in press).

The dikes intrude Eocene plutonic rocks, thus they can be no older than Eocene. Dacitic dikes locally are cut by rhyolitic dikes. Youngest of all of the dikes and crosscutting all others are dark lamprophyric and diabasic dikes. The altered condition of the dikes makes radiometric dating of them uncertain and few dates are available. Zircon from a rhyolite dike at the Little Falls molybdenum deposit (pl. 1) on the South Fork Payette River gave a fission-track age of 29.3±1.7 m.y. (Paul Andriessen, written commun., 1982). A whole-rock analysis of a sample of quartz latite dike, also near the South Fork Payette River, yielded an age of 38.5±1.2 m.y., a date that Armstrong (1976) believed to be probably low. These dates, plus field evidence, suggest that most of the dikes are of Eocene age.

HYDROTHERMAL ALTERATION

Hydrothermal alteration is extensive in plutonic rocks of central Idaho and appears to be directly related to Eocene plutonism. Criss and Taylor (1983) call attention to widespread alteration around Tertiary plutonic bodies and describe the depletion of ^{18}O and deuterium in the altered rocks and the development of propylitic mineral assemblages. Biotite is altered to chlorite and feldspars are clouded by development of sericite. Commonly, the zones of ^{18}O depletion extend well beyond zones of visible alteration (Criss and others, 1985). Extreme hydrothermal alteration, where the rocks are so altered that original composition is difficult to determine, is particularly evident along fault zones and sheared areas. All rocks in the altered areas have been affected by hydrothermal activity, although the older Cretaceous granitic rocks have been more affected. As noted by Criss and Taylor (1983), the water involved in the hydrothermal alteration probably was of meteoric origin and drawn convectively into the area around the Tertiary plutonic "heat engines," particularly along the more permeable zones of faulting and fracturing.

RELATIONS OF MINERAL DEPOSITS TO EOCENE INTRUSIVE ROCKS

Field evidence indicates that many mineral deposits in the Challis quadrangle are genetically related to Tertiary magmatic activity. Typical of these deposits are veins that were worked chiefly for their gold-silver content but which also contain associated lead, zinc, and copper minerals. These veins are common in the Boise Basin area, where they are chiefly in granitic rocks of the Idaho batholith, although extensions of some veins and entire exposures of others are in Eocene rocks of the diorite complex, or in or along dikes that cut the dioritic rocks (Anderson, 1947). Some of the veins are cut by Tertiary dikes (Ballard, 1924), which indicates that dike intrusion and mineralization were essentially contemporaneous. A similar vein-dike relationship occurs in the Banner district where veins follow northeast-striking faults and rhyolite dikes in biotite granodiorite of the Idaho batholith. At least one of the veins crosscuts a rhyolite porphyry dike (Anderson and Rasor, 1934), whereas the northeast continuation of another vein is crosscut by a rhyolite dike.

Silver-gold veins at the Golden Sunbeam mine in the Yankee Fork mining district are in intrusive rhyolite, which contains zircon that has yielded a fission-track age of 45.8±2.3 m.y. (Paul Andriessen, written commun., 1982). Other silver-gold veins at the Singheiser and Rabbit Foot mines in the Gravel

Range mining district also are in Eocene intrusive rhyolite, as are gold-silver veins at Parker Mountain (Kiilsgaard and others, in press). In the Yellowjacket mining district, Anderson (1953) described the source of gold-silver-base metal deposits as early Tertiary magma and noted that ore-bearing fractures cut all dikes except those of lamprophyric composition. Two mines in the Yellowjacket district, the Hisey and White Rabbit (pl. 1), are in hornblende-biotite diorite, a unit of the Eocene diorite complex.

Shenon and Ross (1936) described gold deposits in Challis Volcanic Group in the Thunder Mountain district and presumed that mineralization came from a deep-seated source, from which also came light- and dark-colored dikes that also cut the Challis Volcanic Group. The inference of Tertiary mineralization is supported by exploration of the Sunnyside mine in 1983-84 (J.R. Mangham, written commun., 1984) by Coeur Explorations, Inc., who concluded that gold deposits at the mine formed during waning stages of resurgence of the Thunder Mountain cauldron complex. Shenon and Ross (1936) also noted that gold deposits in the Edwardsburg district, immediately north of the Challis quadrangle, are so closely related to Tertiary dikes that they also are of Tertiary age. The Red Mountain stockwork (pl. 1), 3.5 mi north of Yellow Pine, contains gold, molybdenite, scheelite, and stibnite, which Erdman and others (1985) conclude are related to an underlying Tertiary intrusive.

The Yellow Pine and Meadow Creek mines in the Yellow Pine mining district have been notable producers of gold, antimony, and tungsten. From 1942 to 1944, the two mines, both operated by the Bradley Mining Company, were the largest producers of antimony and tungsten in the United States (Cooper, 1951). Genesis of the deposits is controversial. Currier (1935) believed them to be associated with the Cretaceous Idaho batholith, whereas White (1940) and Cooper (1951) considered them to be of Tertiary age, the latter author basing his opinion, in part, on the occurrence of ore minerals in fractured Tertiary dikes at the Meadow Creek mine. Cooper (1951) also thought the ores were formed during a single period of mineralization related to Tertiary igneous activity in the region. B.F. Leonard, longtime U.S. Geological Survey worker in the Yellow Pine district, concludes that mineralization at the Yellow Pine and Meadow Creek mines is of Tertiary age (personal commun., 1985).

Gold in a rhyolite dike at the Iron Crown mine (pl. 1), northeast of Stanley, has been described by Choate (1962), and our geologic mapping indicates the rhyolite to be of Tertiary age. Gold-silver veins at the Valley Creek and Buckskin mines (pl. 1) are in hydrothermally altered biotite granodiorite of the Idaho batholith, but the zone of alteration and the veins extend along a swarm of northeast-trending Tertiary dikes and appear to be genetically related to them. Gold-silver resources at the two mines have been summarized by Kiilsgaard and Van Noy (1984).

In a general sense, the mineralogy, textures, alteration effects, and regional trends of gold-silver-base metal veins in pre-Tertiary igneous rocks and in igneous rocks of Eocene or younger age are similar over much of the Challis quadrangle. These features indicate that such veins probably were derived during the same or closely spaced mineralizing epochs and from a common source of Tertiary magmatic activity.

Several fluorspar deposits in the Challis quadrangle are in Tertiary igneous rocks and appear to be products of Tertiary magmatic activity. The largest and most productive fluorspar deposits occur as veins and fracture fillings in Challis Volcanic Group near Meyers Cove (Anderson, 1954).

Fluorite-gold-silver veins near the mouths of Big and Little Casino Creeks ($44^{\circ}15'$ N., $114^{\circ}51'$ W.) east of Stanely cut porphyritic granodiorite of the Idaho batholith. In that locality, at the Homestake mine (pl. 1), Choate (1962) has shown that a fluorite-bearing vein cuts a rhyolite dike, mapped as Tertiary by the present authors. Other veins in which fluorite is a principal constituent cut Challis Volcanic Group in the Yankee Fork district (Choate, 1962), and Tertiary granitic and dioritic rocks in the vicinity of the Middle Fork of the Salmon River. Some fluorspar deposits at Keystone Mountain ($44^{\circ}26'$ N., $114^{\circ}21'$ W.), near Challis, are in Paleozoic Bayhorse Dolomite. Anderson (1954) describes fluorite at one of the deposits as occurring along a fault, the hanging wall of which is Challis Volcanic Group, and reports that the fluorite is post-Challis in age and probably of the same age and origin as the Meyers Cove deposits.

Veinlets of molybdenite cut intrusive Tertiary rock at the CUMO and Little Falls deposits in the southwestern part of the quadrangle (Kiilsgaard and Bennett, 1985). At the Little Falls deposit, molybdenite veinlets crosscut a rhyolite dike containing zircon that has yielded a fission-track age of 29.3±1.7 m.y. (Paul Andriessen, written commun., 1982).

Several veins that contain primary uranium minerals cut biotite granodiorite of the Idaho batholith in the area northeast of Stanley. Other uranium-bearing veins in the area are in silicic rocks that intrude the batholith and still others are in sedimentary rocks at the base of the Challis Volcanic Group. Kern (1959) believed the uranium ores in all of the deposits to have been formed contemporaneously from a common source, but Choate (1962) has pointed out that while primary pitchblende is in veins in the batholithic rocks, the bedded uranium minerals in the sedimentary rocks are of secondary origin and probably derived from erosion of the primary pitchblende-bearing veins. The age of primary pitchblende in the veins is not known with certainty, but the fact that radioactive stringers were found in a basalt dike at the P & B property (Choate, 1962), plus the occurrence of pitchblende in northwest-trending faults that cut Tertiary dikes, suggest the pitchblende is of Tertiary age. The pitchblende-bearing veins also have been found to contain stibnite, molybdenite, and gold and silver, minerals commonly found in Tertiary intrusive rocks in nearby mineralized areas.

ALLUVIAL DEPOSITS TERRANE

By Thor H. Kiilsgaard and Frederick S. Fisher

The alluvial terrane consists of unconsolidated or poorly consolidated fluvial deposits of pre-Pleistocene, Pleistocene, or Holocene age. Materials in these deposits are mostly gravel, sand, silt, and clay. Excluded from this terrane are lateral, end, and terminal moraines, talus, landslide debris, alluvial fans, and rock glaciers. Only the larger areas of alluvial deposits are delineated on plate 2; many other deposits are present in and along stream channels but are too small to show at a 1:250,000 map scale.

Gold and radioactive minerals have been mined from the extensive alluvial deposits along several valleys in the Challis quadrangle. The radioactive minerals, chiefly euxenite and monazite, and much of the placer gold have been produced from Pleistocene deposits; some placer gold has been mined from Recent alluvium. Minor amounts of opal have been produced from placer deposits in the eastern part of the quadrangle and Holocene alluvium in many stream channels contains anomalous concentrations of a great variety of metallic minerals useful as indicators of bedrock ore deposits in the drainage. Sand and gravel deposits are abundant and are being produced from several valleys where there is a nearby demand. Small amounts of mercury and tungsten also occur in placer deposits near Stanley and Yellow Pine, respectively.

Two stages of Pleistocene glaciation are known in the quadrangle (Williams, 1961; Mackin and Schmidt, 1956); both formed extensive moraines and outwash fans. Locally, as in Bear Valley (44°22′ N., 115°24′ W.) and Warm Springs Creek (44°09′ N., 114°43′ W.), glacial ice or moraines blocked valleys, impounding streams and forming lakes into which alluvium was fed by eroding periglacial streams. Subsequent erosion of these lake beds or of outwash fans leading away from the moraines has reworked the gravel, carrying away the lighter minerals and leaving behind concentrations of the heavier minerals, including gold and radioactive minerals.

Terraces, formed by several processes, are common along many of the streams in the quadrangle. The presence of gravel on ridges hundreds of feet above valley floors and well away from glaciated areas indicates that some streams were diverted by faulting. Near the head of Kelley Creek (44°17′ N., 114°55′ W.), north of Stanley, perched gravels of this type have been worked for their gold content. Erosion of perched placers has contributed heavy minerals to downstream Holocene alluvium. Some terrace gravels well above stream floors may have been deposited as a result of damming of streams by basalt lava flows, as at Garden Valley and parts of Boise Basin (44°00′ N., 115°55′ W.). Erosion of these terrace deposits also has contributed heavy minerals to younger gravels. Regional uplift causing renewed downcutting created terraces along many of the major rivers in the quadrangle. Excellent examples may be seen along the Salmon River between Stanley and Challis, along Loon Creek downstream from the townsite of Casto, downstream along Camas Creek below Meyers Cove, and along the South Fork of the Payette River. The terraces are mostly cut into solid rock and in general are covered by fluvial gravel and sand. Some of these gravels are only a few feet thick, but in places they are several tens of feet thick; Anderson (1949, p. 11) reports thicknesses of 90 ft locally along the Yankee Fork Salmon River. Many of the richest gold placers were formed in these terrace gravels. The Great Centennial and Centauras mines at Robinson Bar, downstream from Sunbeam along the Salmon River, together produced over 10,000 oz of gold (Choate, 1962, p. 104). Several small but rich placers are located on terraces along Jordan Creek, a tributary to the Yankee Fork Salmon River. Deposits along the Yankee Fork Salmon River have produced over 30,000 oz of placer gold.

The heavy resistant minerals in alluvial deposits originally were constituents of intrusive igneous rocks or of veins or other types of mineral deposits and were released from their original sites through rock decomposition and erosion. Eroding streams transported the released minerals to sites where the stream current was inadequate to move the minerals farther, usually because of decreased stream gradient. Most concentrations of heavy minerals are quite close to the rock from which they were eroded. Lindgren (1898) described placer deposits in the Boise Basin (44°00′ N., 115°55′ W.) that were mined up to the vein outcrop. Placer gold deposits along the Yankee Fork Salmon River and its tributary Jordan Creek are close to the deposits that contributed the gold. Ross (1934b, p. 104) reported that most of the placer gold in the Loon Creek district was derived from lodes only 5 to 10 mi distant. In Bear Valley (44°22′ N., 115°24′ W.), Mackin and Schmidt (1953) found higher concentrations of heavy radioactive placer minerals in the grassroots of weathered granite than at depth in the granite, illustrating that the heavy minerals had lagged behind during erosion whereas lighter minerals had been carried away. This lag effect of heavy minerals in decomposing soil and eluvium has been an important factor in formation of placer deposits in the area.

A conspicuous physiographic feature in the Challis quadrangle is a series of accordant ridges and summit-flats that form a rolling upland surface trenched by steep-walled valleys. This surface, the so-called "Idaho peneplain," is at an altitude of about 7,000 ft in the western part of the quadrangle and is higher to the east. Origin of the upland surface is controversial, as reviewed by Mansfield (1924), but regardless of how it was formed it is clear that the surface took a long time to develop and that bed rocks on the surface are deeply decomposed. Soil on the surface of the summit-flats and soil and eluvium on valley walls was enriched in heavy minerals by the lag in erosional transport, and accelerated glacial erosion delivered enriched concentrations of the minerals to alluvium deposits. Mackin and Schmidt (1953) described the damming of Bear Valley Creek (44°22′ N., 115°24′ W.) by a tongue of early-stage Pleistocene ice, later described as Bull Lake glaciation (Schmidt and Mackin, 1970). Pre-Bull Lake alluvium enriched in euxenite and monazite was deposited behind the dam to form what is now known as Big Meadow. The Big Meadow deposit was drilled by the U.S. Bureau of Mines in 1951 and 1952 (Kline and others, 1953) and dredged for radioactive minerals from 1955 to 1959. The concentration of euxenite on the eastern side of Big Meadow probably was derived from glacial scour of Tertiary intrusive rocks that crop out at the head of Cache Creek (44°17′ N., 115°26′ W.). Casner Creek (44°17′ N., 115°29′ W.), whose alluvial fan is on the east side of Big Meadow (44°17′ N., 115°30′ W.) and which contained the highest concentrations of euxenite mined in the Big Meadow deposit, heads in glacial moraine scoured from the headwaters area of Cache Creek. Downstream from Big Meadow, the content of euxenite and monazite diminished in alluvium derived from later stage Pleistocene glaciation. Holocene downstream alluvium also was low in radioactive mineral content.

In the northwest quadrant of the Challis quadrangle, tungsten has been produced by placer methods from rocks not strictly included in the alluvial deposits terrane. The Quartz Creek mine, located about 2 mi northeast of Yellow Pine, produced about 800 lbs of 60 percent WO_3 concentrates (B.F. Leonard, oral commun., 1984). The ore was hydraulically removed from the hillside on the western side of Quartz Creek. The Springfield Scheelite mine, located near the headwaters of the West Fork Springfield Creek, produced over 118,800 lbs WO_3 in 1954-55 (Cater and others, 1973, p. 210). A considerable portion of the ore was concentrated from scheelite-rich talus.

THE TRANS-CHALLIS FAULT SYSTEM TERRANE

By Thor H. Kiilsgaard and Frederick S. Fisher

The trans-Challis fault system (TCFS) is a major extensional feature in central Idaho consisting of northeast-trending, subparallel, high-angle faults and grabens along which major movement occurred during Eocene time (Bennett, 1984; Kiilsgaard and others, 1986). Within the Challis quadrangle, the TCFS is a broad set of northeast-trending high-angle faults, aligned grabens, a caldera, and roughly aligned Eocene intrusions that extends across the quadrangle from southwest to northeast (pl. 2; fig. 8). This broad structural system has been traced beyond the Challis quadrangle, from the vicinity of Idaho City in the southwest to Leesburg in the northeast, a distance of at least 165 mi. The TCFS is aligned with and appears to be a continuation of the Great Falls lineament of O'Neill and Lopez (1983), who project the lineament northeast from Idaho across Montana. This regional tectonic feature appears to be part of a broad zone of rifting and crustal extension within which fault adjustment has been active since Precambrian time.

Within the Challis quadrangle, we define the trans-Challis fault system terrane as that part of the quadrangle whose structural grain is that of the TCFS. It is coincident with parts of the Idaho batholith, Eocene plutonic rock, Precambrian rock, and Challis volcanic rock terranes, but is identified as a separate and distinct terrane because of the profound controlling influence of the fault system on ore deposition, igneous intrusion, and volcano-tectonic structural development along its entire length.

LOCATION AND GENERAL CHARACTERISTICS

In the southwest quarter of the Challis quadrangle, the trans-Challis fault system is best exposed in an area about 20 mi west-northwest of Stanley. In that area are several major northeast-striking faults that are characterized by white to tan, nonresistant fault gouge in bleached and altered granitic rocks. Some zones of bleached and crushed rock are so pulverized that few fragments are more than 15 in. in diameter. Rocks in the more intensely sheared zone are so altered that their original composition is difficult to determine. Eocene granitic and dioritic rocks are intruded along the fault system as are swarms of associated dikes. Locally, the Eocene plutonic rocks are offset along the faults by post-intrusive left-lateral displacement. Many of the dikes also have been broken and offset by post-dike faulting.

The high-angle faults west-northwest of Stanley are aligned with the Panther Creek graben (Fisher and others, in press; Ekren, 1985), and with the Panther Creek fault and other faults that extend northeast of the Challis quadrangle (Bunning and Burnet, 1981). Only in the area west of Challis (fig. 8; pl. 2) does there appear to be a break in the fault system, but this break is compensated by the Custer graben and the Twin Peaks caldera which are parallel and considered to be part of the fault system. Numerous quartz porphyry and rhyolite dikes, pods, irregular plugs and domes are present in the Custer graben, the Van Horn Peak cauldron complex, and the Panther Creek graben (Fisher and others, in press). Many of these intrusive bodies are linear and coincident with the trans-Challis fault system. The rhyolites were emplaced at high levels in the crust and several reached the surface. Most of the plugs and domes are small (less than 1 mi^2); however, one rhyolite stock and flow complex is exposed over about 75 mi^2 (Hardyman and Fisher, 1985). The rhyolites range in age from 48 to 39 m.y. and can be shown locally to have been emplaced along pre-existing faults of the trans-Challis fault system. In places the rhyolites have been offset by younger faults.

AGE OF FAULTING

Movement along the trans-Challis fault system may have been recurrent from Precambrian to present time. Southwest of Leesburg (north of the Challis quadrangle), the Panther Creek fault offsets the contact between Precambrian Yellowjacket Formation and 1.4-b.y.-old plutonic rock (Lopez, 1981). At the contact locality, the Panther Creek fault is defined in part by tight isoclinal folds in the Yellowjacket Formation; truncation of the folds by the 1.4-b.y.-old plutonic rock indicates Precambrian movement along the fault (O'Neill and Lopez, written commun., 1984). Faults of the system clearly

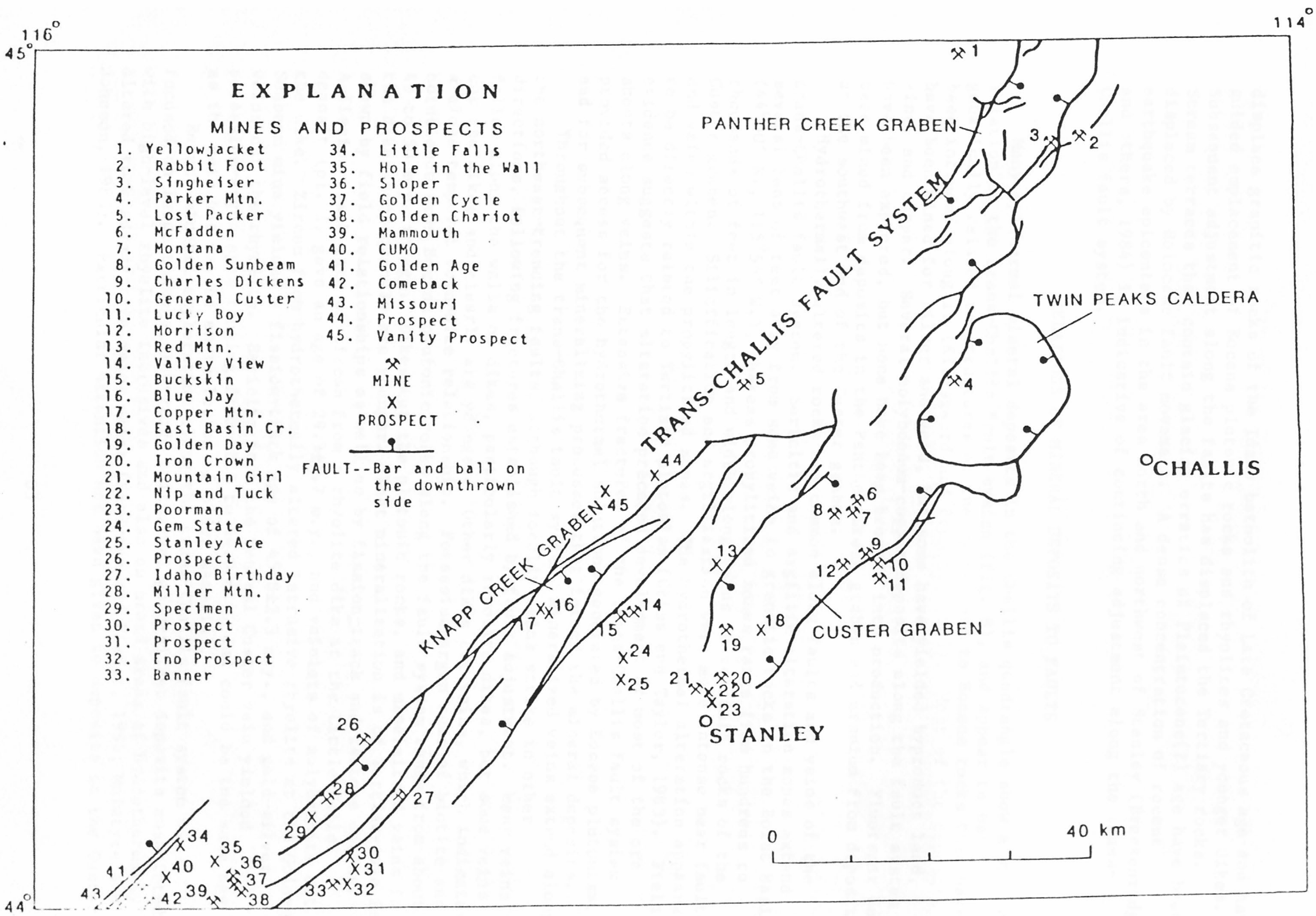

Figure 8 .--The trans-Challis fault system and related mineral deposits

displace granitic rocks of the Idaho batholith of Late Cretaceous age and have guided emplacement of Eocene plutonic rocks and rhyolites and younger dikes. Subsequent adjustment along the faults has displaced the Tertiary rocks. Stream terraces that contain glacial erratics of Pleistocene(?) age have been displaced by Holocene fault movement. A dense concentration of recent earthquake epicenters in the area north and northwest of Stanley (Breckenridge and others, 1984) is indicative of continuing adjustment along the trans-Challis fault system.

RELATIONS OF MINERAL DEPOSITS TO FAULTS

Many epithermal mineral deposits in the Challis quadrangle show a spatial relation to the trans-Challis fault system (fig. 8), and appear to be genetically related to structures of the system and to Eocene rocks that have been intruded along it (Kiilsgaard and Bennett, 1985). Most of the deposits have been mined for silver and gold, but some have yielded byproduct lead, zinc, and copper. Several molybdenum-copper deposits along the fault system have been explored, but none have been brought into production. Fluorspar has been mined from deposits in the Panther Creek graben and uranium from deposits at the southwest end of the Custer graben.

Hydrothermally altered rocks are common along faults and veins of the trans-Challis fault system. Sericitic and argillic alteration zones extend several tens of feet away from some veins in granitic rocks in the Boise Basin ($44^{o}00'$ N., $115^{o}55'$ W.), whereas propylitized zones range from hundreds to thousands of feet in length and width along veins in volcanic rocks of the Custer graben. Silicification and argillization were more intense near faults and veins within the propylitized zones. The hydrothermal alteration appears to be directly related to Tertiary plutonism (Criss and Taylor, 1983). Field evidence suggests that alteration preceded development of most of the ore shoots along veins. Extensive fractures of the trans-Challis fault system provided access for the hydrothermal solutions generated by Eocene plutonism, and for subsequent mineralizing processes that formed the mineral deposits.

Throughout the trans-Challis fault system, mineralized veins extend along the northeast-trending faults, although locally veins strike in other directions, following fractures established by fault adjustment. Many veins follow along the walls of dikes, particularly rhyolite dikes, but some veins cut the dikes and clearly are younger. Other dikes cut veins, which indicates a close temporal vein-dike relationship. Potassium-argon ages of biotite and hornblende from Eocene plutonic rocks along the fault system range from about 45 to 50 m.y. in age. Dikes cut the plutonic rocks, and mineralized veins in the dikes consequently are younger. That mineralization is of Tertiary age is shown by field relationships as well as by fission-track and isotope dating. A fission-track date of zircon from a rhyolite dike at the Little Falls deposit (pl. 1) gave an age of 29.3±1.7 m.y., and veinlets of molybdenite cut the dike. Zircon from hydrothermally altered intrusive rhyolite at the Golden Sunbeam mine yielded a fission-track age of 45.8±2.3 m.y., and gold-silver veins cut the rhyolite. Sericite from the General Custer vein yielded potassium-argon ages ranging from 48.4 to 44.0 m.y. and could be the same age as the vein but may be an inclusion of older material.

Recent mineral exploration along the trans-Challis fault system has focused on large-tonnage, low-grade epithermal gold-silver deposits associated with high-level rhyolite intrusives and also on broad areas of hydrothermally altered rock adjacent to major veins (Hardyman and Fisher, 1985; McIntyre and Johnson, 1985). Particular attention has been given to deposits in the Custer graben, in the vicinity of the Golden Sunbeam and General Custer mines (pl. 1; fig. 8), where gold values are in the range of 0.02 to 0.03 oz per ton. The Lost Packer and Parker Mountain deposits (pl. 1; fig. 8) also have been explored, as have the CUMO, Little Falls, and Idaho Birthday deposits (pl. 1; fig. 8) in the southwestern part of the quadrangle. The Singheiser and Rabbit Foot deposits (pl. 1; fig. 8) in the northeast part of the quadrangle have produced only a few hundred ounces of gold each but may offer targets for large-tonnage, low-grade gold mining operations.

GEOPHYSICAL ANOMALIES IN THE CHALLIS QUADRANGLE

By Michael W. Webring and Don R. Mabey

INTRODUCTION

Regional gravity and aeromagnetic surveys of the Challis quadrangle were designed to define anomalies several square miles in area or larger. These anomalies reflect features of comparable extent and do not reflect more local features such as might be related to individual ore bodies. Data collection and reduction methods are described in Mabey and Webring (1985).

The diverse geology in the Challis quadrangle includes rocks with a wide range of densities and magnetic properties (Mabey and Webring, 1985). The Precambrian metasedimentary rocks have an average density of about 2.7 g/cm^3. Paleozoic sedimentary rocks are generally less dense and average about 2.6 g/cm^3. The granodiorite and two-mica granite that make up the main mass of the Idaho batholith have an average density of about 2.58 g/cm^3, but the tonalite and related rocks in the western part of the batholith are more dense, about 2.67 g/cm^3. The Eocene granites have an average density of 2.56 g/cm^3 and the Eocene diorite about 2.7 g/cm^3. The Tertiary volcanic rocks and the Cenozoic sediments range widely in density and have the lowest average.

Measurements of the magnetic properties of the major rock units are too few to permit calculation of average magnetic properties; however, enough information is available to support qualitative generalizations. The sedimentary and most of the metasedimentary rocks are weakly magnetized; however, magnetite-rich zones in the Precambrian metasedimentary rocks are strongly magnetized. Most of the rocks of the Idaho batholith are weakly to moderately magnetized whereas the Eocene plutons are generally more strongly magnetized. The magnetization of the Eocene volcanic rocks covers a wide range. Some volcanic units are strongly magnetized, with remanent magnetization, both normal and reversed, commonly much greater than the induced magnetization.

REGIONAL GRAVITY AND MAGNETIC FEATURES

Throughout the Challis quadrangle an inverse correlation exists between the Bouguer gravity anomaly values and regional topography. The lowest anomaly values are over the area of highest elevation in the east-central part of the quadrangle and the highest values are over the topographically low area in the southwest. This inverse correlation reflects the general isostatic balance of the region with the high elevations buoyed up by mass deficiencies at great depth.

Superimposed on this broad regional gravity pattern are gravity anomalies of more local extent that reflect mass anomalies in the upper few miles of the crust. The component of the Bouguer gravity anomaly that correlates with regional topography can be subtracted from the complete Bouguer gravity anomaly map to emphasize the more local anomalies. A residual gravity map of the Challis quadrangle was prepared by removing from the complete Bouguer anomaly value for each station the gravity attraction of a layer of rock with a thickness equal to the average elevation within 38.5 mi of the station (fig. 9). Large gravity lows are produced by the Thunder Mountain and Van Horn Peak cauldron complexes. The Eocene granite plutons produce gravity lows and the larger, more mafic Eocene intrusive masses produce gravity highs. Low-density fill underlying the larger valleys produces gravity lows. A large gravity high is approximately coincident with the Bayhorse anticline.

The most extensive variations in the residual magnetic anomaly field (fig. 10) are a broad area of generally low intensity over the Idaho batholith in the west, with superimposed low amplitude local anomalies, and an area of higher intensity in the east with generally higher amplitude local anomalies. Most of the higher amplitude local magnetic anomalies are produced by Precambrian rocks or by Tertiary intrusive or extrusive igneous rocks.

GRAVITY AND MAGNETIC ANOMALIES

The gravity and magnetic anomalies in the Challis quadrangle suggest several major blocks of contrasting lithology and structure; linear zones in the anomaly patterns define lineaments. For presentation in this report the quadrangle is divided into four major blocks of contrasting gravity and magnetic anomalies. The western block is west of the Deadwood fault zone and consists primarily of rocks of the Idaho batholith. The central block includes the eastern part of the Idaho batholith, the major Eocene batholiths and the Thunder Mountain cauldron complex. The Van Horn Peak block is approximately coincident with the Van Horn Peak cauldron complex. The eastern block contains abundant Paleozoic and Precambrian sedimentary and metasedimentary rocks in a complex structural setting and locally intruded by Cretaceous and Eocene plutons and locally overlain by Eocene volcanic rocks and Cenozoic sediments.

WESTERN BLOCK

The western part of the Challis quadrangle is characterized by low magnetic intensity, generally low magnetic relief, and an eastward increase in residual gravity anomaly values. The low magnetic intensity reflects a weakly magnetized zone of the Idaho batholith with no apparent Tertiary intrusives except at Monumental Peak and in a band in the vicinity of Jackson Peak to the southeast. The gravity gradient is probably the combined effect of an eastward thinning of the batholith and an eastward increase in density of the batholith. The negative residual gravity anomaly values define an area where the mass deficiency at depth is greater than required to compensate for the average elevations.

Monumental Peak high.--A combined gravity and magnetic high in the area of Monumental Peak reflects a partly exposed intrusive body of Eocene diorite. The body, which is elongated east-northeast, appears to be dome shaped and substantially more extensive than the surface exposures. This body lies on the north edge of a zone of higher magnetic intensity that extends south along the east side of the western block. Eocene dioritic rocks extending to the Boise Basin area may underlie the area of higher magnetic intensity.

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Figure 9. Residual gravity of the Challis quadrangle.

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Figure 10. Residual magnetics of the Challis quadrangle.

Grimes Creek (44°01′ N., 115°51′ W.) magnetic high.--A zone of high magnetic intensity at the south edge of the western block reflects a zone of exposed Eocene dioritic intrusive rocks, and suggests that a large pluton underlies this area. An appended magnetic high extends north-northeast in part over an exposed diorite stock and in part over a large dike swarm indicating that these dikes make up a substantial volume of the rock mass underlying the anomaly.

Paddy Flat (44°47′ N., 115°57′ W.) high.--A north-trending zone of high magnetic intensity and high Bouguer gravity in the northwest corner of the Challis quadrangle appears to reflect the more dense and more strongly magnetized tonalitic rocks of the Idaho batholith exposed in that area. This area is typical of an area lying largely west of the Challis quadrangle.

CENTRAL BLOCK

A large zone extending north across the central part of the Challis quadrangle is characterized by relatively high average residual gravity anomaly values and high magnetic intensity. In the southern part of the zone, rocks of the Idaho batholith are intruded by Eocene plutons. In the north are a large Tertiary caldera (Thunder Mountain), a large Eocene pluton (Casto pluton), and extensive areas of Idaho batholith and older metasedimentary rocks. The geology and the geophysical anomalies exhibit a northwest and a northeast grain. The consistently positive residual gravity anomaly values indicate a unit of crust that is supported at a slightly higher elevation than can be attributed to local isostatic forces. The relatively high magnetic intensity appears to reflect primarily the Eocene igneous rocks.

Thunder Mountain cauldron complex.--A gravity low is approximately coextensive with the Thunder Mountain caldera. Average magnetic intensity over the low is intermediate between the Idaho batholith and Casto pluton to the east, but includes several local magnetic highs. Maximum gravity relief is about 20 mgal, which could be produced by 14,700 ft of volcanic rock with a density contrast of $-0.1\ g/cm^3$. The gravity low may also in part reflect an underlying pluton. The gravity anomaly suggests a north-trending west edge of the mass anomaly, but the magnetic anomalies have a north-northeast trend. Two magnetic highs lie near the western edge of the Thunder Mountain block. One of the highs crests over an outcrop of Sunnyside tuff. Although this rock contributes to the anomaly, the outcrop of latite is not the principal source. Both highs appear to reflect strongly magnetized units of volcanic rock.

Stibnite magnetic high.--A magnetic high over rocks of the Idaho batholith trends a little north of west from Stibnite. No comparable anomaly is produced by these rocks elsewhere in the Challis quadrangle, and the anomaly suggests a shallow buried intrusive within the batholith. The gravity low in this area is not well defined, but it is possible that it is reflecting the same body. This anomaly may relate to the mineralization in the area.

Casto pluton.--An arcuate gravity and magnetic high lies east and south of the Thunder Mountain cauldron complex. Although the highs are approximately coextensive with the Casto pluton (44°48′ N., 14°49′ W.), they are offset to the southeast. The gravity and magnetic data can be interpreted as indicating that the Casto pluton extends under the Van Horn Peak cauldron complex, and that the mass extends approximately 3 mi southeast of the mapped extent.

Soldier Lakes magnetic high.--An extensive magnetic high in the Soldier Lakes area (44°31′ N., 115°12′ W.) appears to reflect a buried mass with moderate magnetization. A gravity low is approximately coincident with the magnetic high. Small masses of Eocene intrusive rock occur in the area of these anomalies. The anomalies may reflect a larger Eocene pluton.

Grandjean (44°09′ N., 115°10′ W.) magnetic high.--In the southern part of the central block is an area of generally higher magnetic intensity. Detailed surveys in the area of Tenmile Creek, to the south of the quadrangle (Mabey, unpub. data) reveal that the larger local magnetic highs are produced by Eocene intrusive rocks. The entire area of the high may be underlain by Eocene intrusive rock. The area of relatively high magnetic intensity north and west of the Sawtooth batholith probably contains abundant Eocene intrusive rock in the subsurface. The magnetization of these rocks, however, appears to be lower than that of the Sawtooth batholith. No magnetic expression of the large mass of Precambrian Thompson Peak Formation is apparent. The magnetic nose on the west side of the large mass of Thompson Peak may reflect a southward extension of the Eocene intrusive body outcropping to the north.

Sawtooth batholith.--The northeast part of the Sawtooth batholith (44°08′ N., 115°01′ W.) is in the central block part of the Challis quadrangle. A large magnetic high is coincident with the batholith and the form of the anomaly indicates that at least this part of the batholith has steep sides. Kiilsgaard and others (1970) in reporting on the entire batholith concluded that the linear magnetic gradients on the northeast and southwest reflect faults bounding the batholith. Along the eastern part of the northern edge of the batholith the magnetic anomaly suggests that the north edge of the main body producing the magnetic anomaly lies up to 3 mi south of the exposed contact. Thus the part of the Sawtooth batholith lying west of Redfish Lake (44°07′ N., 114°56′ W.) may be relatively thin. Within the batholith a correlation between magnetic intensity and topography is evident. Gravity values decrease eastward across the batholith, but no discrete anomaly coincides with the batholith. The small gravity low that would be expected to reflect the relatively low density of the Sawtooth batholith appears to be confined to the eastern part of the batholith. This may reflect the thickest part of the batholith or a lower density phase.

Sawtooth Valley.--The separation of the near-surface gravity anomaly produced by Quaternary sediments and the broader regional anomaly on which they are both superimposed involves major uncertainties. The gravity low produced by the unconsolidated sediments underlying the valley appears to have an amplitude of less than 10 mgals and probably reflects between 1,640 and 3,280 ft of sediments. The gravity anomaly suggests that normal faults bound both sides of the valley. Sawtooth Valley appears to be a keystone block in the center of the broad topographic arch (fig. 11). The gravity anomaly produced by the batholith appears to have an amplitude of about 15 mgals and be centered under Sawtooth Valley. A mass with density contrast of -0.1 g/cm and 2.1 mi thick would produce the anomaly. The west edge of the anomalous mass is not coincident with the west edge of the Sawtooth batholith as defined by the magnetic anomaly or geologic mapping; however, there is a correlation between the location of the mass and an area of higher magnetic intensity. The eastern extent of the anomalous mass is less clearly defined but is approximately coincident with the easternmost exposures of the Idaho batholith. Modeling of the magnetic high over the Sawtooth batholith (Mabey and Webring, 1985; Criss and Champion, 1984, fig. 13) indicates that the batholith extends under Sawtooth Valley. Thus, the anomalous near-surface mass producing the gravity anomaly may be a composite of the eastern edge of the Idaho batholith and low-density mass under the Sawtooth Range related to the Sawtooth batholith.

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Figure 11. Topographic terrane of the Challis quadrangle.

VAN HORN PEAK BLOCK

The Van Horn Peak block is defined by a large residual gravity low. The zone is approximately coextensive with the Van Horn Peak cauldron complex as defined by McIntyre and others (1982) but differs in detail, particularly along the northwest border.

The regional gravity low, which trends southwest for about 54 mi from the north edge of the quadrangle, is a complex anomaly that appears to be produced by several mass anomalies. Although most of the area of the low is underlain by Eocene volcanic rocks, the anomaly also extends locally along its edges over pre-Tertiary metamorphic rocks, an appendage of the Idaho batholith, and Tertiary intrusive rocks. The anomaly shows a general correlation with the mapped volcanic structures, but important differences exist. Magnetic intensity is generally low over the Van Horn Peak, but four large magnetic highs occur in the area including the highest amplitude magnetic anomaly in the Challis quadrangle.

Prior to the Borah Peak earthquake in 1983, most of the earthquakes in the Challis quadrangle occurred in a northeast-trending zone extending through the Van Horn Peak cauldron complex. Most of these earthquakes have focal depths less than 3.6 mi (Pennington and others, 1974). Although no Quaternary faults have been identified in this zone, the seismic activity suggests that it is a zone of active tectonism.

Panther Creek graben.--In the northern part of the Van Horn Peak block is an area of low gravity closure coincident with Panther Creek graben as defined by McIntyre and others (1982). The gravity anomaly could be produced by about 9,850 ft of graben fill with a $-0.3\ g/cm^3$ density contrast. The anomaly indicates that the prism of thickest fill is bounded on the east by a mapped fault and by a parallel fault about 4-8 mi to the west. The western half of the graben is underlain by thinner fill.

Flume Creek magnetic high.--One of the highest amplitude magnetic anomalies in the Challis quadrangle is a high south of Meyers Cove between Flume Creek ($44^{o}47'$ N., $114^{o}32'$ W.) and Camas Creek. The anomaly appears to reflect a near-surface strongly magnetized body. No gravity stations were established directly over the magnetic body, but adjacent stations define an elongate low with the lowest Bouguer anomaly values at the stations nearest the magnetic body. Part of the gravity low may reflect an extension of the Panther Creek graben, but part is likely related to the source of the magnetic high. Both the gravity and magnetic anomalies indicate an intrusive body at shallow depth.

Challis Creek magnetic high.--The highest amplitude magnetic anomaly in the Challis quadrangle is a high along Challis Creek ($44^{o}34'$ N., $114^{o}20'$ W.) in the southeast part of the Twin Peaks caldera. The anomaly has a shallow source but is not produced by the rocks exposed in the ridge north of Challis Creek. Rather it appears to reflect a concealed near-vertical, elongate mass against the southeast caldera wall. The mass, which is about 3 mi wide and 11 mi long, is strongly magnetized and has a vertical extent of several miles. The body does not have a major effect on the Van Horn Peak regional gravity low. Thus the disturbing mass appears to be a strongly magnetized body with a low density. Although it may be a volcanic unit, the indicated geometry suggests an intrusive body.

Challis Creek Lakes ($44^{o}33'$ N., $114^{o}20'$ W.) gravity low.--Within and along the southeast edge of the Van Horn Peak block is a deep northeast-trending gravity low. The minimum Bouguer anomaly values in this low are the lowest in the Challis quadrangle. Although the very low gravity values reflect in part the isostatic anomaly related to the high average elevation, the low in large part reflects a major low-density mass in the upper crust. The entire area of the low is underlain by Eocene volcanic rocks.

The northeast part of the Challis Creek Lakes low is approximately coincident with the Twin Peaks caldera (Hardyman, 1981; McIntyre and others, 1982), a small gravity closure occurring in the northern part of the caldera. However, on the southwest the gravity low extends beyond the caldera and the lowest gravity values are near the mapped edge of the caldera. In addition to the large Challis Creek magnetic high along the southeast edge of the low, a smaller magnetic high lies near the southwest end of the low. This high reflects a strongly magnetized unit of volcanic rock northeast of Eightmile Creek. Elsewhere within the low, the magnetic intensity is relatively low with several areas of low closure. Some of the lows indicate reversely magnetized rock.

The Challis Creek Lakes low could be produced by either a depression filled with low-density volcanic rocks, a low-density intrusive, or both. The coincidence of the northern part of the low with the Twin Peaks caldera suggests that at least this part of the gravity low is caused by a depression filled with low-density volcanic rocks. The continuity of the gravity anomaly across the southwestern edge of the Twin Peaks caldera and the lack of any magnetic indication of an underlying intrusive suggest that the entire Challis Creek Lakes low is a volcanic depression. Perhaps the Twin Peaks caldera is the youngest part of a more extensive caldera that underlies the Challis Creek Lakes low.

Custer graben.--A gravity trough continues southwest from Challis Creek Lakes low with greatly decreased amplitude over the Custer graben. Only a few hundred feet of Eocene volcanic rock are required to produce the gravity anomaly. Local gravity relief suggests that small local gravity anomalies are present that have not been adequately defined. Magnetic relief is moderate. A gravity high and a small magnetic low in the area of the Golden Sunbeam mine reflect the rhyolite dome of the mine (McIntyre and Johnson, 1983). A similar gravity high astride the graben boundary occurs at Custer. It is related to a buried intrusion and associated alteration (Criss and others, 1985).

The geologic significance of parts of the northwest edge of the Van Horn Peak block as defined by the geophysical anomalies is not apparent. In the Mayfield Creek area the gravity low extends west of the Van Horn Peak caldera complex over a tongue of the Idaho batholith which is locally overlain by metamorphic rocks. Clearly, here the low is not reflecting Tertiary volcanic rock. Northeast of Mayfield Creek is an area of high magnetic intensity (Mayfield Peak magnetic high) with two closed magnetic highs. Part of the southern high is caused by the volcanic rock in Mayfield Peak, but most of the anomaly is not. The magnetic anomaly indicates a block of magnetic rock, probably an intrusive body, northeast of Mayfield Creek and suggests a significant structure coincident with Mayfield Creek. Northeast of the Mayfield Creek area the boundary of the gravity low lies inside the Van Horn Peak cauldron complex suggesting that the volcanic rocks in the vicinity of Sleeping Deer Mountain are unusually dense and relatively thin.

EASTERN BLOCK

A northward-narrowing zone in the eastern part of the Challis quadrangle is characterized by positive residual gravity anomaly values and by a northwest grain of both the gravity and magnetic anomalies. Tertiary volcanic rock is widespread over the zone and Quaternary alluvium covers most of the larger valleys. However, Paleozoic and Precambrian sedimentary rocks are also widespread and appear to underlie the younger rocks in most areas. Numerous small bodies of intrusive rocks of both Mesozoic and Cenozoic age crop out, but only one body is more than a few square miles in area. In contrast to the zones to the west where Cretaceous and Tertiary igneous rocks make up most of the upper crust, the eastern zone appears to be underlain by an upper crust composed of sedimentary and metasedimentary rocks presumably resting on an older basement complex. The geophysical anomalies and the geology of this part of the Challis quadrangle are similar to the anomalies and geology of a large region to the southeast. The positive residual gravity anomalies are part of a very extensive anomaly that covers most of eastern Idaho and a large region to the east where the land surface is at a slightly higher elevation than can be attributed to isostatic forces (Mabey and Webring, 1985). The north-northwest trends parallel the basin and range structures of eastern Idaho and the volcanic rifts of the eastern Snake River Plain.

Three major valleys extend north-northwest from the eastern Snake River Plain to the vicinity of the Salmon River. The southern parts of these valleys are part of a closed drainage basin whose lowest area is on the northwest side of the Snake River Plain. The northern parts of the valleys drain into the Salmon River. All three valleys are major depressions with structural relief ranging up to 3.5 mi. Large gravity lows in these valleys reflect low-density Cenozoic rocks up to 2.5 mi thick underlying the valleys (Bankey and others, 1985). Two of these regional valleys extend into the Challis quadrangle. The north end of Pahsimeroi Valley (44°40′ N., 114°02′ W.) is an extension of Little Lost River Valley. Round Valley (44°30′ N., 114°10′ W.), Big Antelope Flats (44°18′ N., 114°05′ W.), and Little Antelope Flats (44°23′ N., 114°08′ W.) are extensions of Big Lost River Valley.

The epicenter of the Borah Peak earthquake in 1983 was a few miles southeast of the Challis quadrangle (Richins and others, 1985). This earthquake, which had a Richter magnitude of 7.3, produced a surface rupture along about 22 mi of the Lost River fault zone extending southeast from Antelope Flat near the east edge of the Challis quadrangle. An extensive aftershock series extended well into the Challis quadrangle but was largely confined to the eastern block. This earthquake was dramatic evidence of the active nature of basin and range faulting in the region.

Pahsimeroi Valley.--A few miles east of the Challis quadrangle a gravity low of about 30 mgals occurs in Pahsimeroi Valley (44°40′ N., 114°02′ W.) indicating about 6,500 ft of low-density Cenozoic rocks underlying that part of the valley. However, the gravity anomaly decreases rapidly toward the northwest and within the Challis quadrangle has an amplitude of only a few mgals. The gravity data indicate that concealed structural relief of Pahsimeroi Valley decreases abruptly toward its northwest end. The gravity low in Pahsimeroi Valley and in the Little Lost River Valley is asymmetrical with the steepest gradient on the east side and the lowest gravity values east of the center of the valley. The gravity anomaly indicates that the valley is an eastward-tilted fault block. The location of the river west of the structural low in the valley suggests that recent faulting has not kept pace with the deposition of alluvium in the valley. That volcanic rocks underlie the alluvium in the valley is indicated by the magnetic anomaly data, and a substantial part of the low-density material underlying the valley may be volcanic.

Big Lost River trough.--The name Big Lost River trough is here applied to the elongate depression that extends 78 mi south-southeast from the north end of Round Valley (44°30′ N., 114°10′ W.) to the Snake River. Although this feature consists of several segments, it appears to be a continuous structural feature.

The gravity low in Round Valley and Big and Little Antelope Flats is smaller than that in Pahsimeroi Valley and more complex. The low is more extensive than the floor of the valley, and volcanic rock is at the surface over much of the area of the anomaly. A major part of the low must reflect a thickened area of volcanic rocks upon which the valley is superimposed. Local steepening of the gravity gradient on the east side of Round Valley, along with the location of the Salmon River along the east side of the valley, indicate eastward tilting of the valley floor. However, the asymmetry of the gravity anomaly associated with the part of the Big Lost River trough that is in the Challis quadrangle is not well developed. To the southeast in the Thousand Springs area and in the Big Lost River Valley an asymmetry similar to that in Pahsimeroi Valley is apparent.

The major valleys (Lehmi, Pahsimeroi, Big Lost River) in east-central Idaho appear to be basin and range structures similar in size, trend, and gravity expression to the valleys in southeastern Idaho (Bankey and others, 1985). Seismic data from southeastern Idaho reveal that most of the major valleys are bounded on the east by westward-dipping listric faults that flatten to merge with low-angle detachment faults. Apparently, late Cenozoic extension has produced reverse movement on faults that developed during an earlier period of crustal shortening. The termination of the major basin and range structure in the Challis quadrangle at the trans-Challis fault system may reflect either a change in the stress field or a disruption of the older thrust faults that controlled the development of the younger structures.

Herd Lake (44°07′ N., 114°10′ W.) trough.--In the southeast corner of the quadrangle an area of volcanic rocks is separated from Big Antelope Flat and Thousand Springs Valley by a zone of Paleozoic sedimentary rocks. The Paleozoic sedimentary rocks are reflected by a gravity high bounded on the west by an elongate gravity low. This gravity low has an amplitude of about 10 mgals and appears to indicate a trough of low-density rocks about 4,900 ft thick, referred to here as the Herd Lake trough. The gravity anomaly suggests that the greatest thickness of low-density rock underlies the high topography in the Jerry Peak-Herd Lake area. To the south the trough terminates at the northeast-trending canyon of the Big Lost River. The Herd Lake trough parallels the valley to the east and may be a similar structure without recent subsidence. A large negative magnetic anomaly in the Jerry Peak area reflects volcanic rocks with a strong reversed remanent magnetization.

Iron Creek magnetic high.--A large magnetic high extends southeast from Moyer Peak through the Iron Creek area (44°55′ N., 114°05′ W.) to the east border of the quadrangle. On the magnetic map of Idaho this anomaly continues to the southeast for a total length of about 60 mi (Zietz and others, 1978). The anomaly occurs over areas where Precambrian metasedimentary rocks, mostly quartzites, either crop out or are stratigraphically likely to occur in the shallow subsurface. In the Challis quadrangle the correlation between topographic highs and the highest magnetic intensity indicates that the magnetic unit extends to the surface over part but not all of the extent of the anomaly. In the Iron Creek area magnetite-bearing zones in the Yellowjacket Formtion are coincident with the crest of the magnetic high. Bouguer gravity values increase northeast across the area of the Iron Creek magnetic high, but there is no obvious gravity anomaly coincident with the magnetic anomaly.

In the Challis quadrangle the magnetic anomaly has an amplitude of about 200 gammas at a flight level 3,200 to 6,500 ft above the surface. The magnetic body producing the anomaly is about 3 mi wide. Very likely it is a magnetite-rich body of quartzite no more than a few miles thick. The Precambrian rocks in this area are displaced by overthrust faults, but details of the structure are difficult to map because of the similarity of the geologic units and poor exposures. If the magnetite zone is a stratigraphic horizon, the magnetic anomaly can be used in unraveling the structure of the Precambrian rocks. If it does not correlate with a stratigraphic unit, it defines a 60-mi-long zone of mineralization. The northwest part of the magnetic anomaly is approximately coincident with the zone of cobalt mineralization extending southeast from the Blackbird mine. However, the zone of highest amplitude of the magnetic anomaly terminates abruptly a few miles southeast of the mine.

Magnetic anomalies with similar character but lower amplitude are associated with rocks of the Belt Supergroup in northwest Montana. Kleinkopf and others (1972) report that in three areas these anomalies are produced by magnetite in the Burke Formation at the base of the Ravalli Group. Ruppel (1975) suggests the Ravalli Group correlates with the lower part of the Lemhi Group which overlies the Yellowjacket Formation in the Challis area.

Table Mountain ($44^{\circ}48'$ N., $114^{\circ}13'$ W.) low.--Lying between the exposed Precambrian rocks in the Taylor Mountain area and those along the Salmon River to the south is a 12-mgal gravity low which is here called the Table Mountain low. In the area of the gravity low, elevations are relatively high in the Table Mountain-Ward Butte area ($44^{\circ}50'$ N., $114^{\circ}12'$ W.) on the west and low in the Hat Creek drainage ($44^{\circ}47'$ N., $114^{\circ}03'$ W.) on the east. The low, which is approximately equidimensional, occurs in an area of Tertiary volcanic rock. The gravity low is coincident with the Corral Creek cauldron segment (fig. 1), and appears to reflect a local depression containing about 0.5 mi of volcanic rock. Considerable magnetic relief occurs over the southern part of the low. The Table Mountain low is separated from a major low to the west by a high approximately coincident with Morgan Creek (pl. 1).

Bayhorse high.--West of Round Valley and the Herd Lake trough is an area of high Bouguer gravity values, which is here called the Bayhorse high. Sedimentary rocks of known or inferred Paleozoic age crop out over most of the northern and central part of the Bayhorse high but are largely covered with Tertiary volcanic rock in the southern part. Although part of the gravity high is produced by the density contrast between the Paleozoic rocks and the Cenozoic rocks, a major part of the high reflects a positive mass anomaly within or underlying the Paleozoic rocks. The Bayhorse high is parallel to and about 1.2 mi east of the axis of the Bayhorse anticline. The gravity high is terminated abruptly on the north by the Van Horn Peak cauldron complex and on the west is bounded by a zone of high gravity gradient. The amplitude of the gravity high decreases rapidly southward near the confluence of the East Fork Salmon River and Herd Creek ($44^{\circ}09'$ N., $114^{\circ}68'$ W.), but a low-amplitude high continues about 6 mi south of the quadrangle. On the east the anomaly is bounded by the Herd Creek trough and the Big Lost River trough. Anomaly values in the Lost River Range east of the Big Lost River trough are only a few milligals lower than in the Bayhorse area, and the regional mass anomaly may extend under the eastern valleys.

A broad zone of high magnetic intensity extends northwest over much of the Bayhorse high. At the north end of this zone is the very high amplitude magnetic high over rocks of the Van Horn Peak cauldron complex. Although much of the high-intensity zone is over Tertiary volcanic rocks, Paleozoic sedimentary rock is at the surface over most of the area of highest intensity. Clearly the regional magnetic high is not produced by the volcanic rock. The peak of the magnetic anomaly is on the west side of the Juliette stock (44°23′ N., 114°22′ W.), a 98-m.y.-old (McIntyre and others, 1976; recalculated) quartz monzonite-granodiorite intrusive that is thought to be related to the Ramshorn-Skylark silver-bearing vein system. A drill hole on the crest of the Bayhorse anticline penetrated an altered intrusive dated as 93 m.y. (S.W. Hobbs, oral commun., 1981). In the Bayhorse high, small gabbro dikes and sills occur, particularly near the thrust faults. The source of the magnetic high is near the surface in the north but deepens to about 1.8 mi in the south. The magnetic zone appears to consist of two major components--a north-trending block about 18 mi wide and generally more than 9,800 ft below the surface, and a superimposed smaller body less than 9,800 ft below the surface. The deeper source extends under the southern part of the eastern valleys.

The oldest rocks exposed in the Bayhorse anticline (fig. 3) underlie rocks of known Ordovician age and are thought to be of Cambrian age. These include about 1,650 ft of dolomite which is probably the most dense sedimentary rock in the quadrangle. The known thickness of these rocks in contact with quartzite would produce a small gravity high, but simply elevating them in the anticline has little effect on the gravity anomaly. The major source of the gravity high must underlie the exposed sedimentary rocks.

The gravity high may reflect a topographic high on the Precambrian crystalline basement or an underlying intrusive complex. Most of the pre-Tertiary rocks in the eastern part of the Challis quadrangle are displaced tens of miles by low-angle thrust faults and the original relationships between the rocks within the several allochthons are not known. The rocks in the Bayhorse anticline may be an autochthon or an allochthon overlying a basement high. The other possibility, that a large intrusive complex may underlie the Bayhorse high, is suggested by the extensive magnetic high apparently at least in part produced by the 98 m.y. Juliette stock. McIntyre and others (1976) consider this stock to be a satellite of the Idaho batholith, but the large mass of rock underlying the Bayhorse high is both more dense and more strongly magnetized than the main mass of the Idaho batholith. The gabbro dikes and sills suggest that a mafic intrusive may underlie the area.

In the Thompson-Slate Creek area (pl. 1) the gravity high extends westward beyond the area of high magnetic intensity. Paleozoic rocks underlie this area but there is no evidence of a major underlying block of magnetic rock.

Two gravity lows lie near the west edge of the Bayhorse high. The Bayhorse Lake (44°24′ N., 114°24′ W.) low, which is inferred to lie within the Bayhorse high, is underlain by Tertiary volcanic rock. It is coincident with a nose on the northwest corner of regional magnetic high. A similar gravity low occurs in the area of Big Lake Creek (44°10′ N., 114°27′ W.). This low is also underlain by volcanic rocks and appears to be reflected by a low-amplitude magnetic high. The Bayhorse Lake and Big Lake Creek lows may indicate thickened volcanic rocks or buried intrusives.

Sheep Mountain magnetic high.--A magnetic high in the area of Sheep Mountain appears to reflect both the volcanic rock at the surface and an underlying pluton. The two effects are difficult to isolate and the anomaly could be produced entirely by the volcanic rock, although the form of the anomaly suggests a deeper component. The depth to the top of the inferred pluton cannot be accurately estimated with the existing data, but it appears to be within one kilometer of the surface. Geologic mapping (Fisher and others, in press) has shown that the Sheep Mountain area is a dacitic volcanic center characterized by numerous porphyry dikes and pervasive propylitic alteration, confirming the inference of a buried pluton.

Thompson Creek magnetic highs.--Four local magnetic highs in the Thompson Creek area appear to reflect Tertiary plutons. The southernmost is produced by the pluton east of the Thompson Creek molybdenum mine (pl. 1). The others occur over Tertiary volcanic rock.

Little Boulder Creek magnetic low.--The most intense magnetic low in the Challis quadrangle lies west of the East Fork of the Salmon River in the Little Boulder Creek area (44°04′ N., 114°32′ W.). The anomaly occurs over volcanic rock and has a near-surface source. It presumably indicates surface or near-surface volcanic rock with strong reversed magnetic polarity.

White Cloud Peaks magnetic high.--A prominent magnetic high in the southern part of the White Clouds Peaks is associated with a large stock. The magnetic anomaly indicates that in the subsurface the stock extends northwest of the exposed contact and thins to the northeast.

Pigtail Creek magnetic high.--A magnetic high in the Pigtail Creek area (44°05′ N., 114°44′ W.) appears to indicate a more highly magnetized phase of the Idaho batholith along its eastern border. The south half of the western edge of the anomaly is coincident with the surface contact between the batholith and the older sedimentary rocks, thereby indicating a high-angle contact. To the north the contact lies about 4 km east of the anomaly. Here either the more magnetized phase of the batholith does not extend east to the contact or the batholith is thin near its edge.

LINEAMENTS

Numerous linear features can be identified on the gravity and magnetic maps of the Challis quadrangle; however, two are particularly prominent and are likely to have important regional significance. The most prominent lineament is a northeast-trending feature extending across the southeastern part of the quadrangle. It is coincident with major segments of the Yankee Fork Salmon River and Challis Creek (pl. 1) and is here called the Yankee Fork lineament. Somewhat less prominent is a northwest-trending feature in the central and eastern part of the quadrangle, here called the Mayfield Creek lineament for the area where the associated geophysical anomalies are most apparent.

Yankee Fork lineament.--The Yankee Fork lineament is a prominent feature on both the gravity and magnetic maps, but is probably best expressed in the residual gravity anomaly. Throughout most of its length the lineament forms the northwest edge of the gravity high that dominates the southeast part of the quadrangle. Its southwest part forms the northwest edge of the lowest part of the gravity low over Sawtooth Valley (44°05′ N., 114°51′ W.) and Sawtooth batholith. It also forms the northwest end of an extensive magnetic high in the Bayhorse area and of the most highly magnetized part of the Sawtooth batholith. Several small magnetic features also reflect the lineament. The lineament is the northwest edge of the area of extensive exposures of Paleozoic sedimentary rocks. Although the Yankee Fork lineament is approximately parallel to the trans-Challis fault system, the two features are probably related.

The Yankee Fork lineament extends in both directions beyond the Challis quadrangle for a total length of about 135 mi. It is approximately parallel to the eastern Snake River Plain and other prominent northeast-trending features in the western United States. Magnetic data outside of the quadrangle can be interpreted as indicating 6 to 9 mi of left-lateral offset along the lineament.

Mayfield Creek lineament.--The Mayfield Creek lineament is best expressed in the magnetic data. It forms the southwest edge of an extensive area of generally higher magnetic intensity and is reflected in several local anomalies. The lineament coincides with the southwest limit of the highest gravity values associated with the Bayhorse anticline and the southwest edge of the lowest gravity values in the Van Horn Peak cauldron complex. Although it appears to coincide with the southwest edge of the Casto pluton, the correlation with geology and topography is not impressive.

CONCLUSIONS

The complex structure and lithology of the crust in the Challis quadrangle are reflected in the gravity and magnetic anomalies. In the eastern part of the quadrangle the larger gravity and magnetic anomalies are associated with features involving rocks ranging in age from Precambrian through Holocene in a complex structural setting. In the central part of the quadrangle the larger anomalies are produced by Eocene extrusive and intrusive igneous rocks. Here, Cretaceous rocks of the Idaho batholith appear to be abundant in the subsurface, but there is no strong geophysical evidence for an older basement complex. In the west the gravity and magnetic fields are relatively subdued with the larger anomalies reflecting Eocene plutons within the Idaho batholith.

GEOCHEMISTRY

By Kathleen M. Johnson

INTRODUCTION

A wide variety of geochemical studies have been done in the Challis quadrangle. A stream-sediment sampling program was undertaken to supplement earlier regional studies and to provide information on regional geochemical trends. Topical and site-specific studies were done in the course of investigations whose primary goals were not necessarily geochemical. These studies commonly focused on a specific rock or deposit type; the geochemical study was typically designed to characterize the rock or deposit type and to improve geochemical prospecting techniques. Results of most of these studies have been published; a few are still in progress. This chapter summarizes the methods and major findings of both the regional studies and those topical or site-specific studies that are complete enough to warrant such discussion.

REGIONAL STUDIES

INTRODUCTION

The objectives of the regional stream-sediment program were to provide information on geochemical trends, to relate those trends to specific lithologic units or structural features, and to locate areas with anomalously high concentrations of one or more elements. In addition, the maps produced after data analysis were used by project geologists in the assessment of mineral resource potential. Sampling was done in the summers of 1979, 1980, and 1981 by J.E. Callahan, G.J. Neuerburg, and others. The following descriptions of sample design and analytical technique are partially derived from unpublished manuscripts by the samplers.

Previous studies in the quadrangle included reconnaissance stream-sediment sampling programs in four areas (pl. 1): the Sawtooth Primitive Area (Kiilsgaard and others, 1970), the Idaho Primitive Area[1] (Cater and others, 1973), the Sawtooth National Recreation Area (Tschanz and others, 1974), and the Ten Mile West Roadless Area (Kiilsgaard, 1982). These areas were not resampled for this study.

In addition, the National Uranium Resource Evaluation Program (NURE) conducted a reconnaissance stream-sediment sampling program in the Challis quadrangle. Most of the 1,511 sediment, 243 ground water, and 248 surface water samples were collected in August-October 1979. Because the purposes of the NURE sampling program were different from those of our study, the two were carried out independently. Marked differences in sampling density, sample media collected, and analyses performed make direct comparison of the results difficult at best. The results of the NURE work are reported in Thayer and Cook (1980), Cook and Fay (1982), and Fay and Cook (1982).

SAMPLING TECHNIQUES

In the parts of the quadrangle that were sampled for this project, first and second order streams were sampled because the restricted nature of the drainages suggests that sediment obtained is likely to be representative of lithologies and mineral occurrences drained. Individual sample sites were chosen on the basis of local stream density and accessibility. Generally only those sample sites that were within 15 to 30 minutes' walk from the vehicle, either helicopter or truck, were sampled. Sample density is about 1 sample per 2 square miles.

At each sample site three samples were collected from the active stream channel: a stream-sediment sample, a panned concentrate, and a water sample. In dry stream beds the samples were collected from what appeared to have been the active channel. Stream-sediment samples included sand-, silt-, and clay-sized fractions. Samples for panning were taken from sand or gravel accumulations in the channel and sieved through a 10-mesh (2.0 mm) stainless-steel screen into a standard 40-cm gold pan. These samples were then panned at the site until approximately 225 grams (approximately 1/2 pound) of sample remained or until most of the quartz, feldspar, organic material, clay-sized material, and rock fragments had been removed. A water sample was also obtained at each site where water was available.

Stream sediments and panned concentrates were air dried and then processed either in a mobile field laboratory (1979) or in U.S. Geological Survey laboratories in Golden, Colo. (1980 and 1981). Water samples were analyzed in the field camp.

ANALYTICAL TECHNIQUES

The minus-200 mesh (<0.074 mm) fraction of the sediment was chosen as the fraction to analyze, based on the results of a brief orientation survey carried out in the Thompson Creek (pl. 1) drainage in 1979 (Callahan and

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[1]Now included in the Frank Church-River of No Return Wilderness.

others, 1981a, 1981b). The survey showed that the contrast between background and anomalous levels for molybdenum and tungsten could be increased by using the minus-200 mesh fraction, rather than the more conventional minus-80 mesh fraction of the sediments.

In the panned concentrates, the best sample medium for outlining deposits containing molybdenum and tungsten was found to be the nonmagnetic heavy mineral separate. The heavy-mineral fraction was separated using bromoform (specific gravity 2.89) and was further subdivided, using a Frantz Isodynamic Separator[2], into three fractions: a strongly magnetic fraction, a weakly magnetic fraction, and a nonmagnetic fraction. The nonmagnetic fraction was scanned with a binocular microscope for the presence of sulfide minerals and gold, examined for fluorescent minerals with a short-wave ultraviolet light, weighed, and then ground for analysis.

The selected fractions of stream-sediment and panned concentrate samples were analyzed spectrographically for 31 elements using standard U.S. Geological Survey semiquantitative techniques described by Grimes and Marranzino (1968). Spectrographic results were obtained by visual comparison of spectra derived from the sample against spectra obtained from standards made from pure oxides and carbonates. The values are reported by giving the nearest midpoint on a six-step scale that uses 1, 1.5, 2, 3, 5, 7, 10 ..... as the midpoints of the intervals. J.E. Callahan (written commun., 1983) concluded that the precision of the analyses for this study conforms closely to that reported by Motooka and Grimes (1976) and is approximately plus or minus one reporting interval at the 83 percent confidence level and plus or minus two intervals at the 95 percent confidence level.

For most of the elements analyzed, values are reported in parts per million (ppm). For iron, magnesium, calcium, and titanium, values reported are weight percent. For convenience, table 6 provides conversions between ppm, percent, and ounces per ton.

Water samples were analyzed for pH and conductivity within 24 hours of collection. No other analyses were done and the samples were discarded.

STATISTICAL TREATMENT OF DATA

The synthesis of geochemical information and interpretation of geochemical distribution patterns depend on statistical analysis of the data. Analysis of data for the Challis quadrangle was complicated by the fact that the data came from several sources over a period of nearly 20 years. Because of the large volume of data, most statistical manipulations were done on U.S. Geological Survey main-frame computers, using the Rock Analysis and Storage System (RASS) and STATPAC series programs (Van Trump and Miesch, 1977).

In order to achieve complete coverage of the Challis quadrangle for this report, five different data sets were used. The study undertaken specifically for CUSMAP resulted in collection and analysis of 2,516 stream-sediment and 2,359 panned-concentrate samples (McDanal and others, 1984). A total of 233 samples were collected from the Ten Mile West Roadless Area (Kiilsgaard, 1982). The Idaho Primitive Area wilderness study (Cater and others, 1973)

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[2]Use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

Table 6.--Conversion of parts per million to percent and to ounces per ton and vice versa

[Conversion factors: 1 lb avoirdupois = 14.583 oz troy; 1 ppm = 0.0001 percent = 0.0291667 oz troy per short ton = 1 gram per metric ton; 1 oz per ton (Au or Ag) = 34.286 ppm = 0.0034286 percent]

Parts per million to percent to ounces per ton			Ounces per ton to percent to parts per million		
Ppm	Percent	Oz per ton	Oz per ton	Percent	Ppm
0.01	0.000001	0.0003	0.01	0.00003	0.3
.02	.000002	.0006	.02	.00007	.7
.05	.000005	.0015	.05	.00017	1.7
.10	.00001	.003	.10	.00034	3.4
.20	.00002	.006	.20	.00069	6.9
.30	.00003	.009	.30	.00103	10.3
.40	.00004	.012	.40	.00137	13.7
.50	.00005	.015	.50	.00171	17.1
.60	.00006	.017	.60	.00206	20.6
.70	.00007	.020	.70	.00240	24.0
.80	.00008	.023	.80	.00274	27.4
.90	.00009	.026	.90	.00309	30.9
1.0	.0001	.029	1.0	.00343	34.3
10.0	.001	.292	10.0	.03429	342.9
20.0	.002	.583	20.0	.06857	685.7
50.0	.005	1.458	50.0	.17143	1,714.0
100.0	.01	2.917	100.0	.34286	3,429.0
500.0	.05	14.583	500.0	1.71	17,143.0
1,000.0	.10	29.167	1,000.0	3.43	34,286.0
10,000.0	1.00	291.667	10,000.0	34.29	342,857.0

provided 197 samples. Sampling in the Sawtooth Primitive Area (Kiilsgaard and others, 1970) yielded 342 samples. Tschanz and others (1974) collected approximately 1,600 samples from the part of the Sawtooth National Recreation Area (SNRA) that is within the Challis quadrangle. Of these, only 462 were used for this study, in an attempt to keep sampling density about the same across the quadrangle. Thus, the total number of samples used for this study was 3,750.

The five data sets are not completely compatible, because of changes in methods and purposes over the years. In the CUSMAP geochemistry program, stream-sediment samples and panned concentrates were analyzed for 31 elements by spectrographic methods. In the Ten Mile West study, stream-sediment samples were analyzed for the same 31 elements by spectrographic methods. The stream-sediment samples from the SNRA were analyzed for 30 elements by spectrographic methods. The data from the Idaho Primitive Area are limited to those available in the published report, which includes spectrographic analyses of stream-sediment samples for 18 elements and 3 types of chemical analyses. The data from the Sawtooth Primitive Area are similarly limited to the published report, but include spectrographic analyses of stream-sediment samples for 24 elements. Another important difference between the various data sets is in the detection limits. Over the years the limits below which various elements can be measured have changed, in some cases considerably. In order to minimize comparison between incompatible groups of data, the samples were handled in two separate groups. The Idaho Primitive Area data and the Sawtooth Primitive Area data were combined and treated as one data set. The stream-sediment samples from the other three areas were combined into one large set. Limits of determination for this data set are shown in table 7.

The purpose of statistical analysis of the two data sets was to define anomalous levels of the various elements for which data are available. Some of these elements are useful in outlining areas with potential for as-yet undiscovered mineral deposits. Other elements are more useful in the general characterization of geochemical trends. The primary tool for defining anomalous levels is a histogram of frequency of occurrence versus analytical value. Because geochemical distributions commonly approximate log-normal distributions, all data were converted to logs before the histograms were plotted. This allows the part of the distribution curve that falls above the detection limit for each element to be treated as a part of a normal distribution curve. A complete set of distribution histograms is shown in figures 12 and 13.

Anomalous levels are those that are in the upper 1-2 percent of the values reported and are well above geochemical abundances reported by Levinson (1980). Where necessary, anomalous levels were adjusted by inspection of the histogram. The purpose of this inspection was to avoid selecting apparently anomalous levels that are really nothing more than the normal tailing out of elemental distribution in unmineralized rocks and to avoid assigning anomalous levels that are actually too high owing to extensive mineralization. Anomalous levels are shown in table 8. A single anomalous sample is not considered significant; it may represent only variability resulting from sampling or analytical techniques. Clusters of anomalous samples are considered significant. The clusters may be either many samples in one geographic area that are anomalous in the same element or a few samples that are anomalous in several elements.

Table 7.--Limits of determination for spectrographic analysis of stream-sediment samples and nonmagnetic heavy-mineral-concentrate samples (from McDanal and others, 1984)

Element	Lower determination limit for minus 200-mesh stream sediments	Lower determination limit for nonmagnetic heavy-mineral concentrate	Upper detection limit
	Percent		
Iron (Fe)	0.05	0.1	20
Magnesium (Mg)	.02	.05	10
Calcium (Ca)	.05	.1	20
Titanium (Ti)	.002	.005	1
	Parts per million		
Manganese (Mn)	10	20	5,000
Silver (Ag)	0.5	1	5,000
Arsenic (As)	200	500	10,000
Gold (Au)	10	20	500
Boron (B)	10	20	2,000
Barium (Ba)	20	50	5,000
Beryllium (Be)	1	2	1,000
Bismuth (Bi)	10	20	1,000
Cadmium (Cd)	20	50	500
Cobalt (Co)	5	10	2,000
Chromium (Cr)	10	20	5,000
Copper (Cu)	5	10	20,000
Lanthanum (La)	20	50	1,000
Molybdenum (Mo)	5	10	2,000
Niobium (Nb)	20	50	2,000
Nickel (Ni)	5	10	5,000
Lead (Pb)	10	20	20,000
Antimony (Sb)	100	200	10,000
Scandium (Sc)	5	10	100
Tin (Sn)	10	20	1,000
Strontium (Sr)	100	200	5,000
Vanadium (V)	10	20	10,000
Tungsten (W)	50	100	10,000
Yttrium (Y)	10	20	2,000
Zinc (Zn)	200	500	10,000
Zirconium (Zr)	10	20	1,000
Thorium (Th)	100	200	2,000

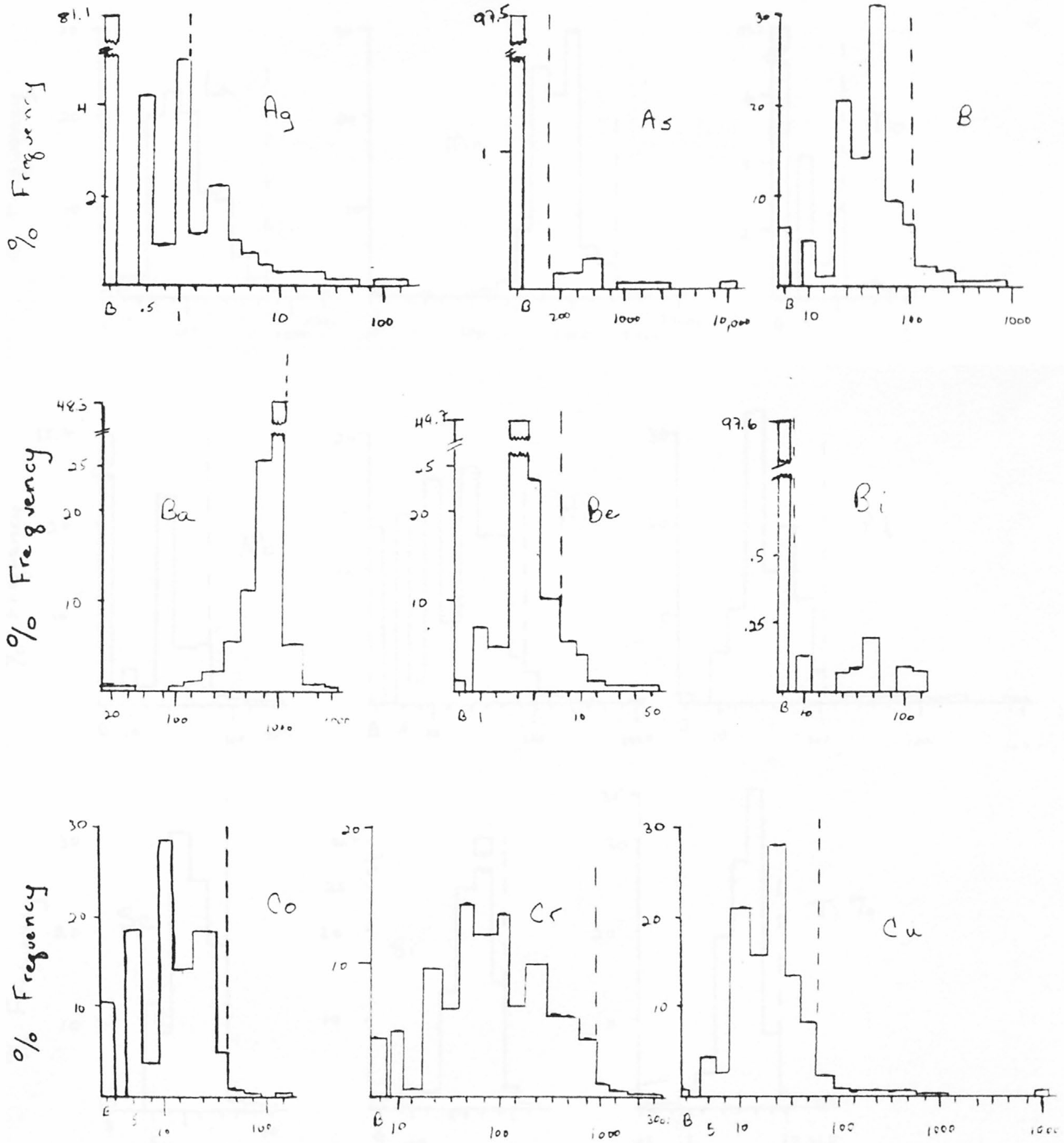


Figure 12. Histograms for geochemical data. All values reported in ppm, except Ti, which is in percent. Values to the right of the dashed line are considered anomalous. B, below limits of detection. A, Spectrographic analyses of stream-sediment samples from Challis CUSMAP, Ten Mile West, and SNRA. N = 3,211. B, Spectrographic analyses of panned-concentrate samples from Challis CUSMAP. N = 2,359.

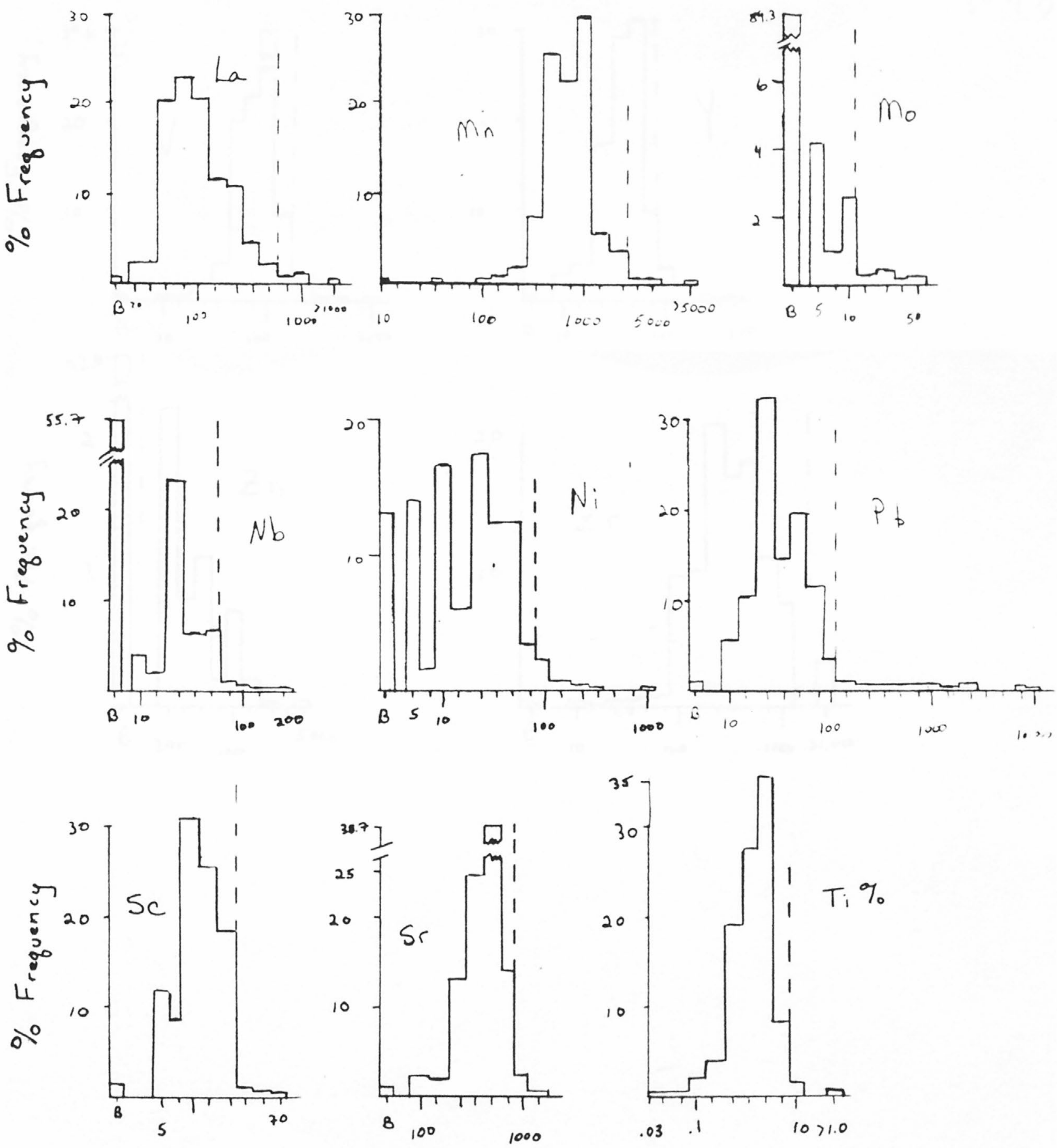


Figure 12A. Continued

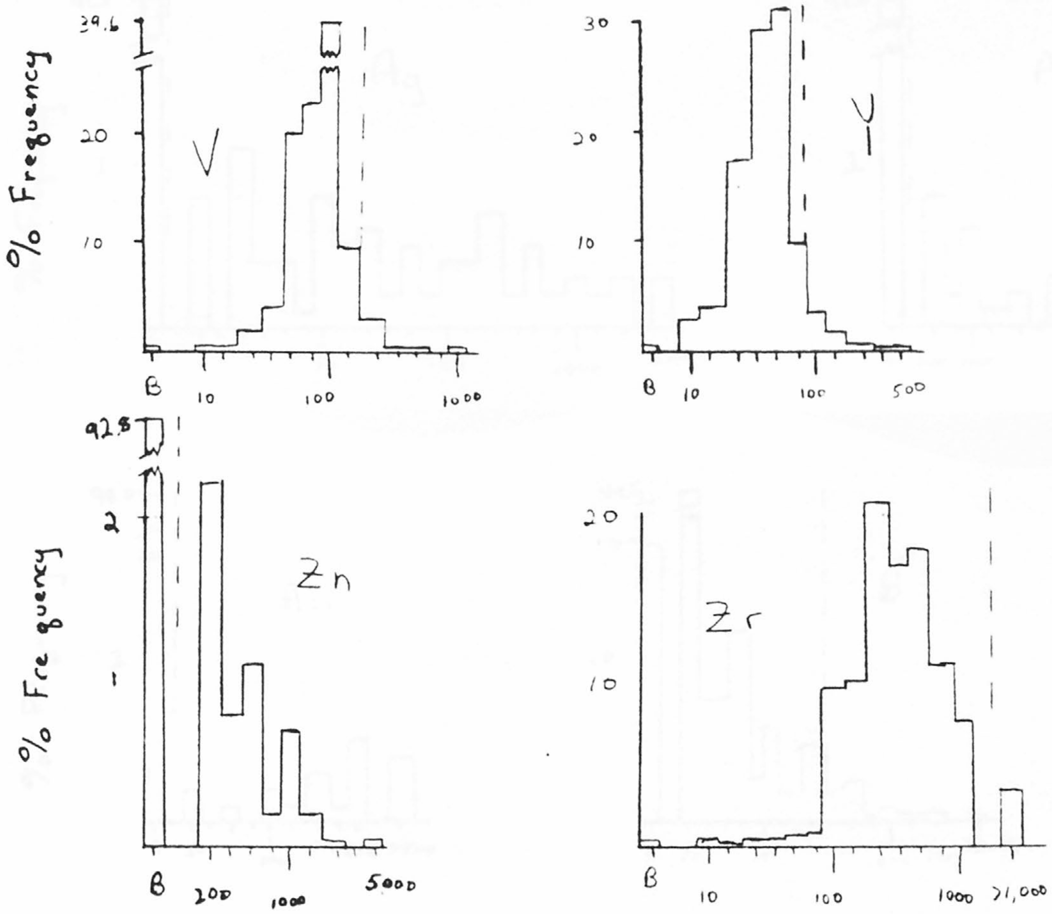


Figure 12A. Continued

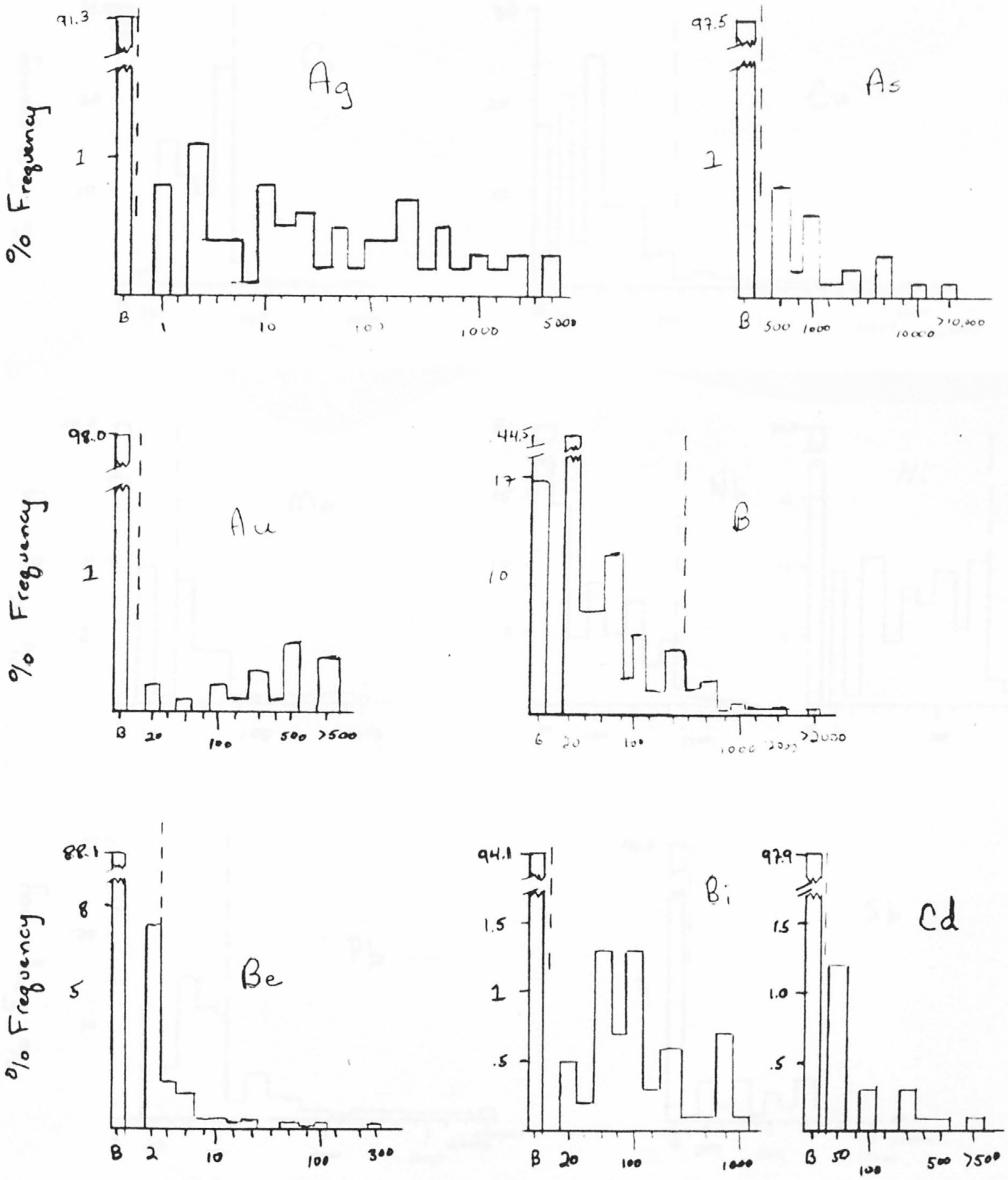


Figure 12B. Continued

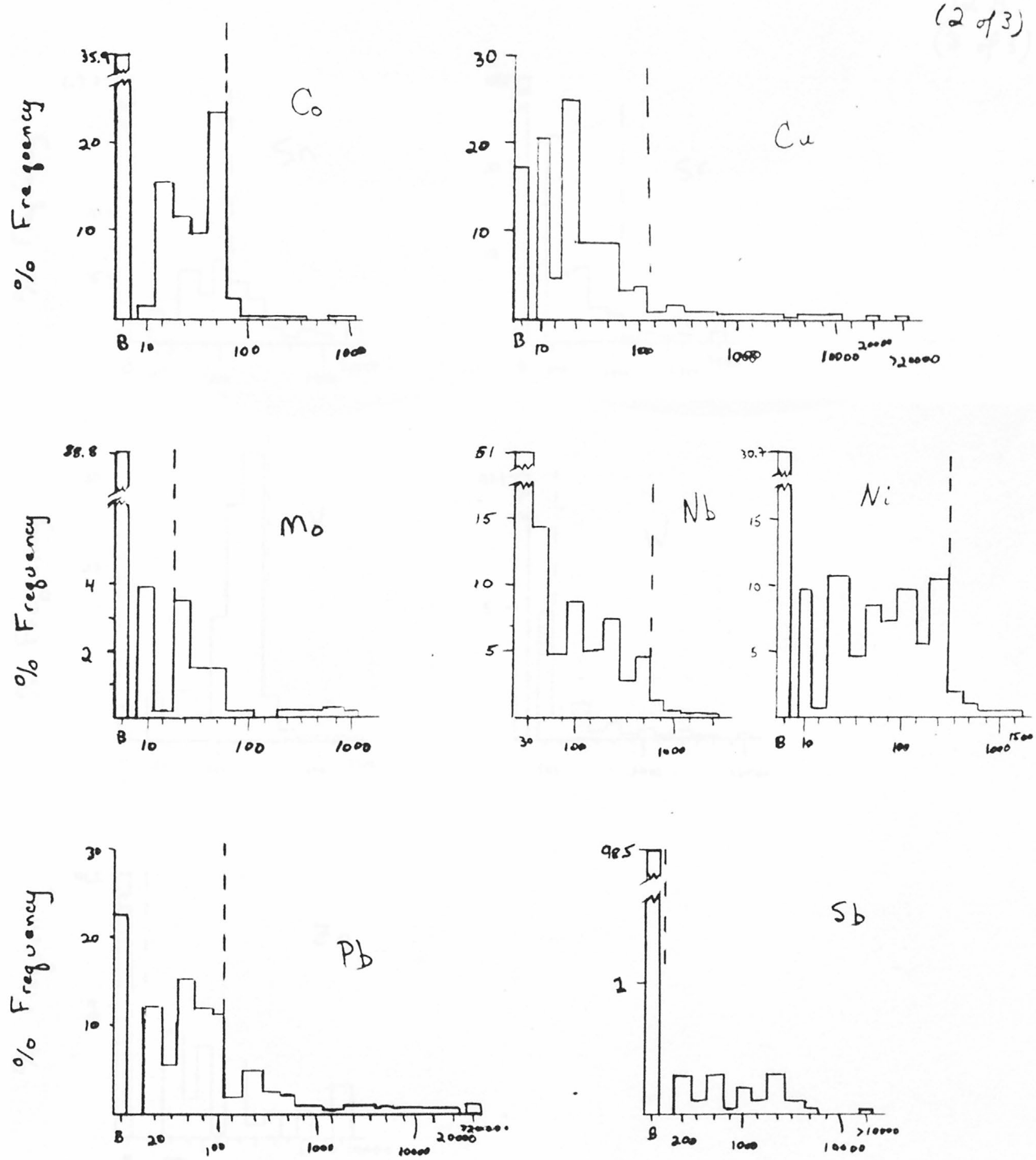


Figure 12B. Continued

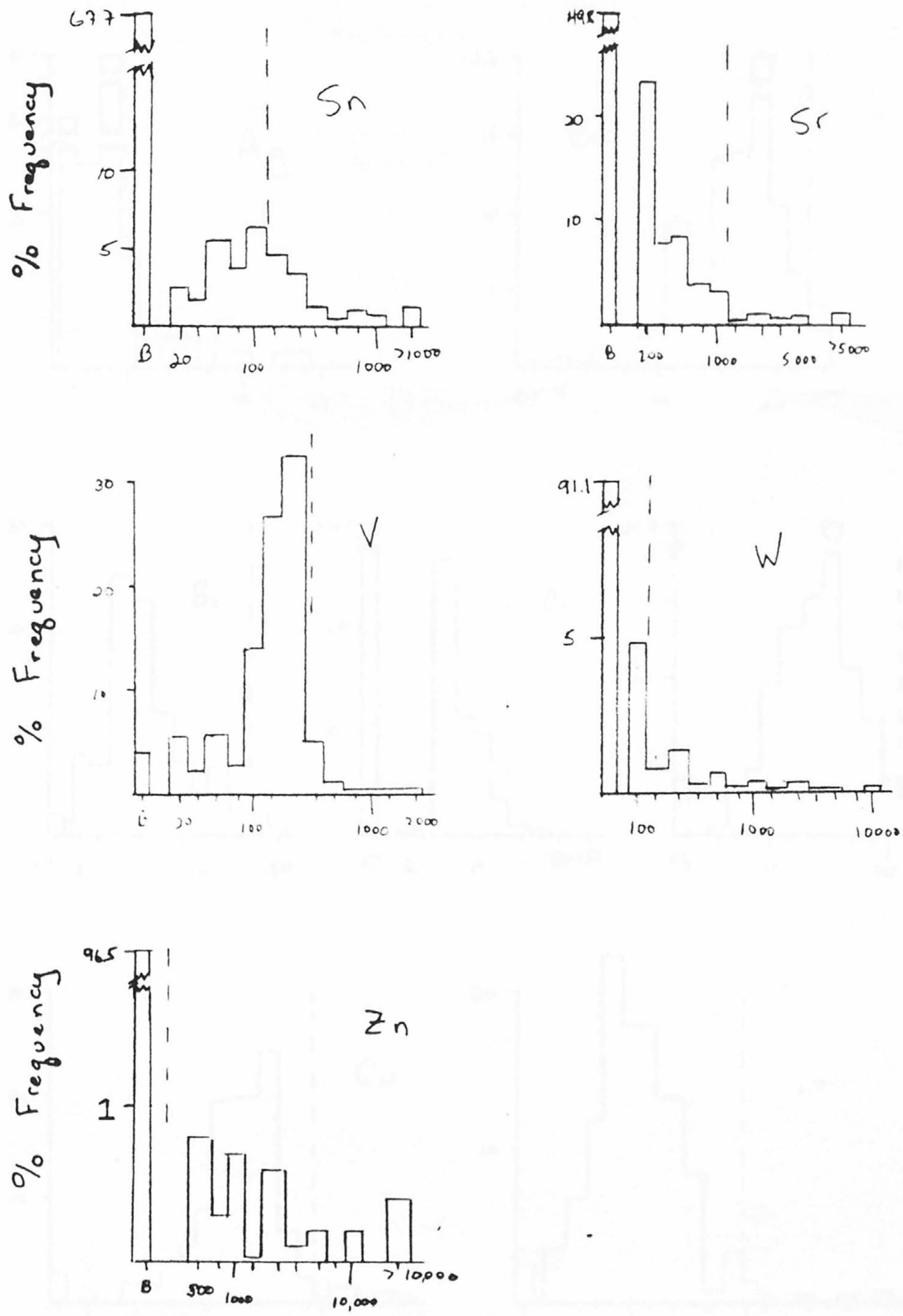


Figure 12B. Continued

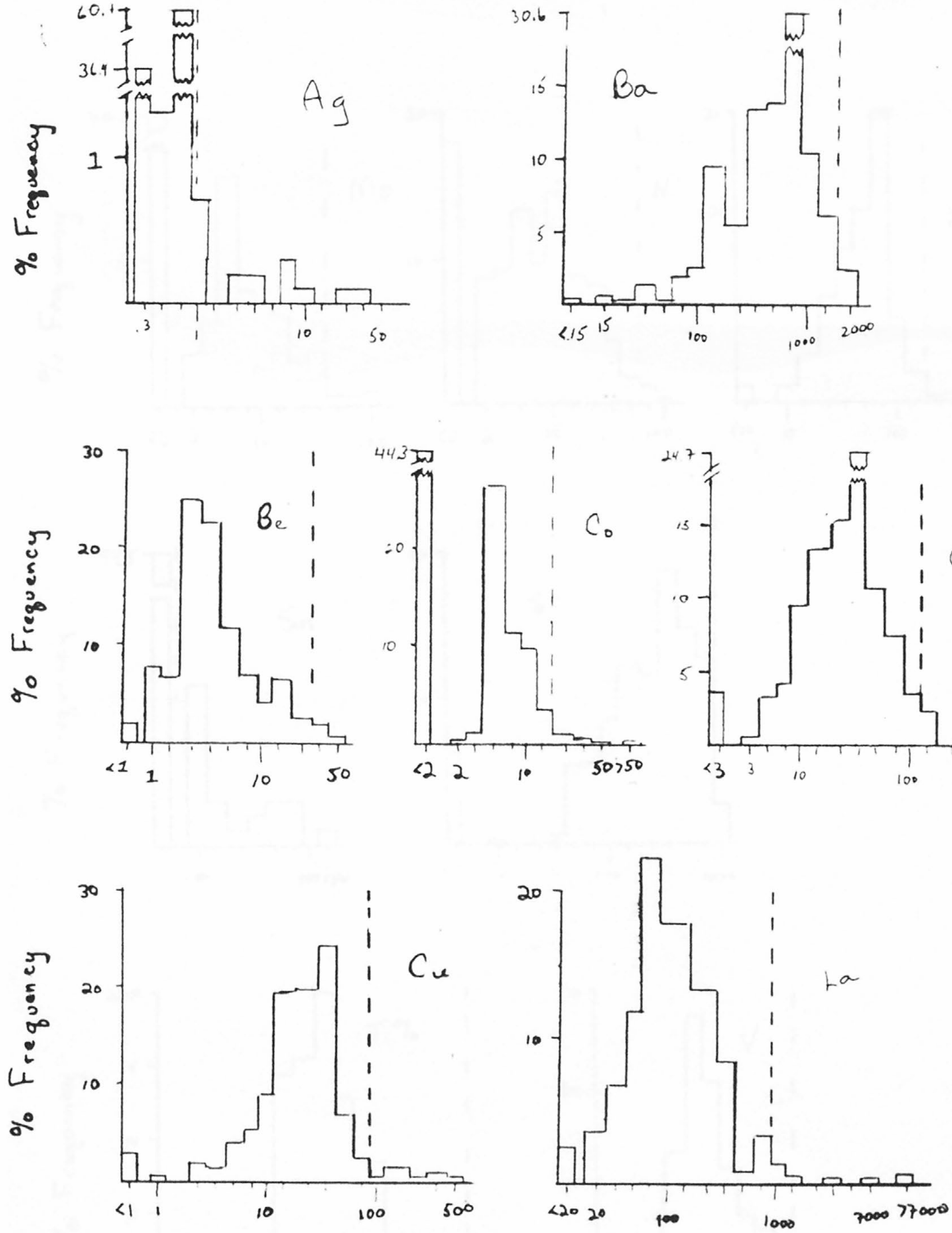


Figure 13. Histograms for spectrographic analyses of stream sediment samples from Sawtooth Primitive Area and Idaho Primitive Area. N=539. All values reported in ppm, except Ti, which is in percent. Values to the right of the dashed line are considered anomalous.

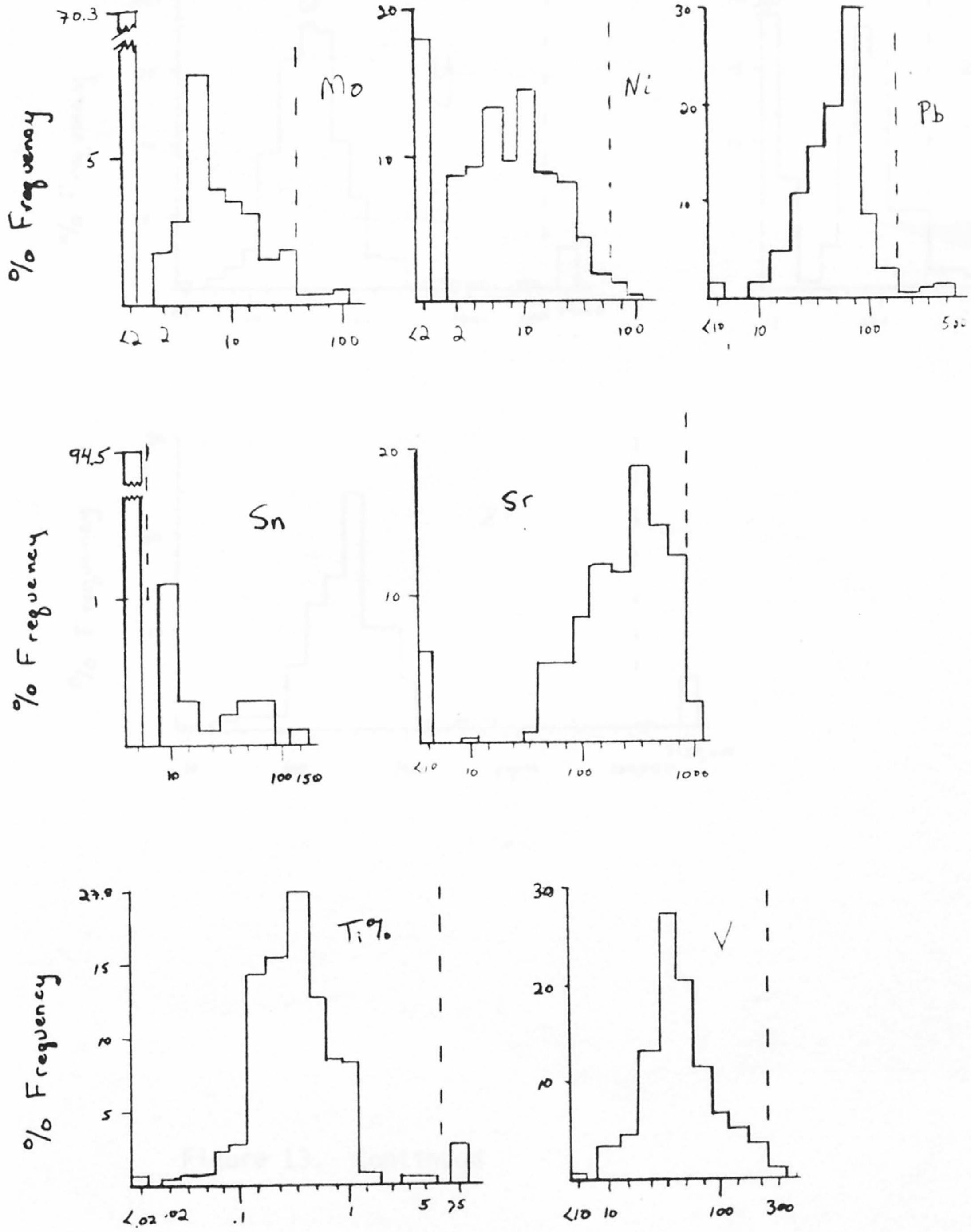


Figure 13. Continued

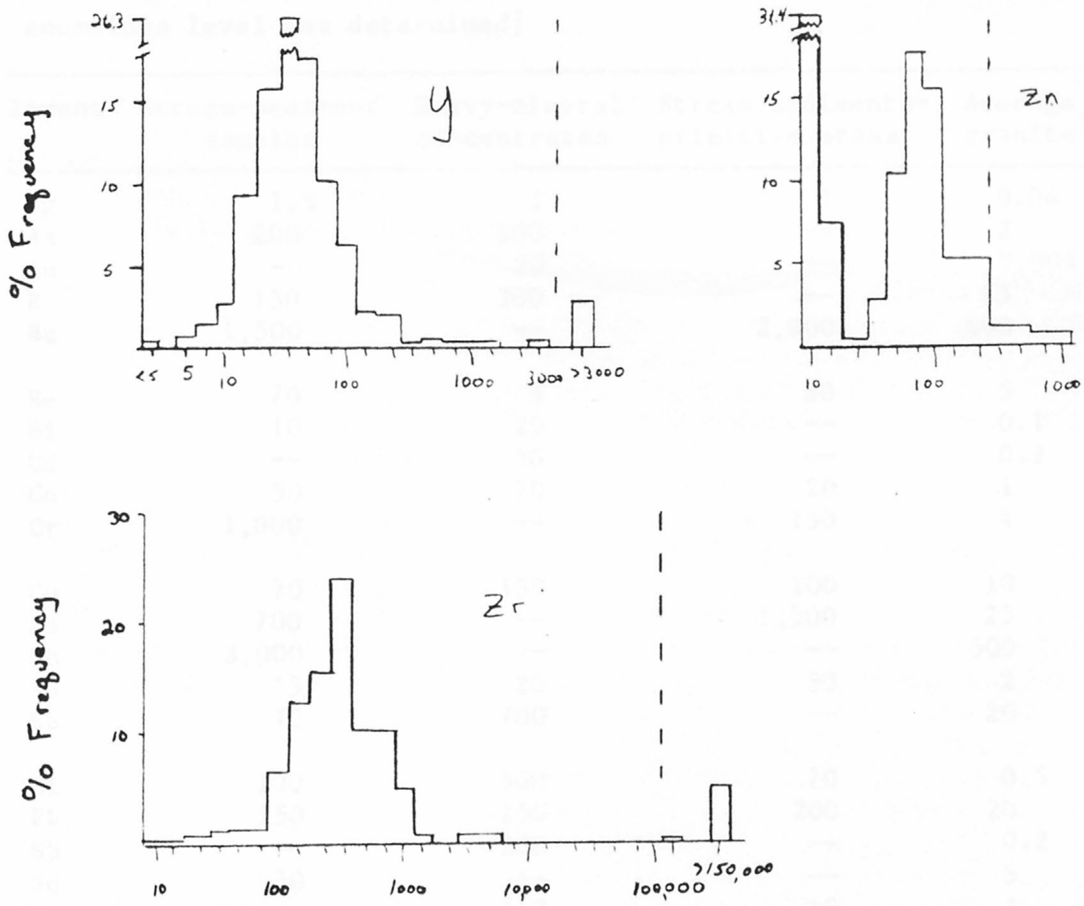


Figure 13. Continued

Table 8.--Anomalous levels for stream-sediment and heavy-mineral-concentrate samples, and geochemical abundances for average granite and average shale

[All values reported in ppm, except Ti, which is in percent; --, means no anomalous level was determined]

Element	Stream-sediment samples	Heavy-mineral concentrates	Stream sediments-primitive areas	Average granite[1]	Average shale[1]
Ag	1.5	1	1	0.04	0.05
As	200	500	--	2	15
Au	--	20	--	0.004	0.004
B	150	300	--	15	100
Ba	1,500	--	2,000	600	700
Be	70	3	30	5	3
Bi	10	20	--	0.1	0.18
Cd	--	50	--	0.2	0.2
Co	50	70	20	1	20
Cr	1,000	--	150	4	100
Cu	70	150	100	10	50
La	700	--	1,500	25	20
Mn	3,000	--	--	500	850
Mo	15	20	50	2	3
Nb	70	700	--	20	20
Ni	100	300	70	0.5	70
Pb	150	150	200	20	20
Sb	--	200	--	0.2	1
Sc	30	--	--	5	15
Sn	--	150	10	3	4
Sr	1,000	1,500	1,000	285	300
Ti	1	--	>5	0.2	0.5
V	200	300	300	20	130
W	--	150	--	2	2
Y	100	--	>3,000	40	35
Zn	200	500	300	40	100
Zr	>1,000	--	150,000	180	160

[1]From Levinson (1980).

RESULTS

After inspection of histograms, anomalous values were plotted on geologic maps for comparison with rock units, structures, and known mineral deposits. Maps at 1:250,000-scale are available as U.S. Geological Survey Miscellaneous Field Studies maps (Johnson and others, in press). Rather than repeat those maps here, this report provides page-size summary maps of selected elements that have particular significance to the quadrangle-wide appraisal of geochemical trends and to the mineral resource assessment.

The reader is cautioned to consider the influence of the complex geology and the data-handling techniques on the reported results of this survey. The geologic map of the Challis quadrangle shows more than 100 rock units (Fisher and others, in press); at best these units can be combined into seven terranes, based on similarities in rock type and geologic history (pl. 2). However, data from the various geochemical sampling programs have been analyzed without regard to the nature of the rocks in each sample's source area. The effects of this combination of circumstances are difficult to measure, but can be imagined readily. Differences in rock type may mask truly anomalous levels of elements whose average concentration varies a great deal between rock types. A hypothetical example of this phenomenon can be seen in the element nickel, whose average concentration in granodiorites is 20 ppm, in shales is 70 ppm, and in basalts is 150 ppm (Levinson, 1980). In a single data set covering an area with all three rock types, the basalts would have the highest nickel values. Plotting those highest values on a map would result in a pattern that showed the extent of basalts. Granodiorites that were in fact enriched in nickel might not even appear--although if a cluster of high nickel values did appear in granodiorite, this would likely be a true anomaly. These limitations could be overcome if the statistical analysis were done on samples that had been separated by rock type, but the difficulties inherent in these procedures are such that they were not cost-effective for this regional study. Subtle anomalies are thus not likely to be recognized in these data sets, both because of the problems described above and because of the sample spacing. Large departures from average concentrations will still be found. Regional trends and concentrations along major structures may be somewhat obscured, but not entirely hidden.

Another cautionary note is in order for users of the maps shown here. Because the data were handled as two separate data sets, anomalous levels are not necessarily the same within and outside the two large primitive areas. This is a result of the process by which the levels were chosen. Also, one should use caution interpreting trends based on concentrations within one data set or the other. What appear to be trends may actually only reflect different anomalous levels.

Figure 14a shows locations of anomalous gold in panned concentrates for the newly sampled areas of the quadrangle. Most of the samples fall within the trans-Challis fault system and many are from areas with productive gold deposits. The locations shown along Johnson Creek (pl. 1) and the South Fork Salmon River (pl. 1) in the northwest part of the quadrangle are not closely associated with any major gold deposits. Mitchell and others (1981) show several gold occurrences in the South Fork Salmon River. Johnson Creek drains numerous mines and prospects reported to contain gold, silver, copper, antimony, and tungsten (Mitchell and others, 1981).

Beryllium also occurs mostly within the trans-Challis fault system. Figure 14b shows that most of the anomalous samples are located in the part of the trans-Challis fault system that is in Challis Volcanic Group. Perhaps

This figure is not available in the open-file version of this manuscript.

Figure 14. Maps showing distribution of anomalous values for selected elements. A, Gold in nonmagnetic heavy mineral concentrates. B, Beryllium in stream sediments. C, Tungsten in nonmagnetic heavy mineral concentrates. D, Lead, zinc, and copper in stream sediments. E, Cobalt, chromium, nickel, scandium, and vanadium in stream sediments.

this reflects the incompatibility of Be and its tendency to concentrate in the late phases of igneous rocks. The trans-Challis fault system was active for some time after the eruption and consolidation of the Challis Volcanic Group; it would have been a good pathway for late beryllium-bearing fluids. The other important hosts for beryllium are the Idaho batholith and Sawtooth batholith, both of which contain beryllium-bearing pegmatites.

Anomalous values of tungsten in panned concentrates are unevenly dispersed in a northwest-trending zone (fig. 14c). This trend appears to agree well with the distribution of tungsten mines and prospects, although lack of panned concentrate samples in the primitive areas and Sawtooth National Recreation Area makes a complete comparison impossible. The stream-sediment data are no help in this matter because of the high detection limit for tungsten determined by semiquantitative spectroscopy and the generally low concentration of tungsten in rocks.

Base metals occur in a number of deposit types across the Challis quadrangle. The distributions of stream-sediment samples with anomalous lead, zinc, and copper are shown in figure 14d. Lead and zinc occur in the black shale terrane, in a northwest-trending zone through the center of the quadrangle, and in the southwest corner of the quadrangle. The Salmon River assemblage, one of the units included in the black shale terrane (Hall and Hobbs, this volume, p. 29), has been shown to have enriched levels of many metals (Fisher and May, 1983), and base-metal vein deposits are also known to occur in the area, making the anomalies not altogether unexpected. The northwest-trending zone of lead-zinc anomalies is roughly coincident with the belt of tungsten values described above. Base- and precious-metal vein deposits are common in the Grimes Pass, Summit Flat, and Banner mining districts (pl. 1), in the southwest corner of the quadrangle, providing a likely source for the lead-zinc anomalies found there. Some copper occurs in the areas with lead-zinc anomalies, but copper alone shows anomalous values in the northeast corner of the map area. This distribution suggests that copper is associated with Precambrian metasediments. Roof pendants in the Idaho batholith may account for the scattered distribution of copper in the western part of the area.

Figure 14e shows the distribution of anomalous values for cobalt, chromium, nickel, scandium, and vanadium. Most of the points shown on the map fall within the Challis volcanic rock terrane and are in streams draining lower andesitic and dacitic units. This concentration appears to reflect the relatively mafic nature of these rocks and to have no particular meaning as a clue in the search for new mineral deposits. The scattered distribution of vanadium in a northeasterly trend across the center of the quadrangle does not correlate with any particular rock unit, terrane, or structure, but does overlap the belt of tungsten, lead, and zinc anomalies discussed above.

TOPICAL AND SITE-SPECIFIC STUDIES

INTRODUCTION

Three types of topical or site-specific geochemical studies have been done as a part of the Challis CUSMAP program. One group has as its purpose the chemical characterization of specific rock types or terranes. Other studies were undertaken to provide information about chemical characteristics of various mineral deposits and their host rocks. The third group is biogeochemical studies of selected plants and mineral deposits. The following descriptions are brief summaries of the goals, methods, and findings of each of the studies that is complete enough to be discussed. The results of many of these projects have been published; the cited references provide more specific information. The observations and conclusions reported are those of the project authors and are not original here.

GEOCHEMISTRY OF THE SALMON RIVER ASSEMBLAGE

Fisher and May (1983) collected 257 rock samples from an area of about 100 km^2 to test the potential of the Salmon River assemblage as a host for syngenetic metallic ore deposits. The Salmon River assemblage is a thick accumulation of turbidite deposits, composed of argillite, siltstone, calcareous siltstone, quartzite, sandstone, and carbonate beds, that was thrust eastward during the Sevier orogeny. These rocks are now exposed in the south-central part of the quadrangle and are included in the black shale terrane (Hall and Hobbs, this volume, p. 29).

Rock chip and grab samples were analyzed by semiquantitative spectrographic and atomic absorption methods. Comparison with published reports of metal concentrations in black shales shows that the rocks sampled are enriched in several elements. The elements most consistently enriched are silver, barium, copper, molybdenum, vanadium, and zinc. Other elements that occur in anomalous concentrations are arsenic, gold, boron, cadmium, lead, antimony, and tin. Fisher and May report correlations between molybdenum, zinc, and vanadium and between silver and vanadium, but otherwise find no significant correlations. They suggest that the lack of correlation may result from either original metal distribution, post-depositional introduction or redistribution of metals, or biased sampling.

ROCK GEOCHEMISTRY OF THE IDAHO BATHOLITH

The Atlanta lobe of the Idaho batholith, as exposed in the western part of the Challis quadrangle, includes tonalite, hornblende-biotite granodiorite, porphyritic granodiorite, biotite granodiorite, muscovite-biotite granite, and leucocratic granite. These six rock types were emplaced during at least three periods of magmatic activity (Kiilsgaard and Lewis, 1985) and range in age from about 95 to 72 m.y. Continuing studies (Lewis and others, 1985) of these rocks show that the tonalite has I-type mineralogy and chemistry, the muscovite-biotite granite has many characteristics of S-type granites, and the biotite granodiorite has characteristics of both S- and I-type granites.

Lewis and others also report a systematic variation in major element chemistry of the batholith. Samples collected along a 10-km traverse, 30 km east of the west margin, show a rapid increase in SiO_2 towards the east, with a corresponding decrease in CaO, MgO, and Al_2O_3. Minimal chemical variation occurs eastward across the next 90 km. Rocks along the east margin contain less SiO_2 and more CaO, MgO, and Al_2O_3 than core rocks, and are similar to the rocks of the west margin, except that mineralogic, textural, and chemical variations are less systematic in the east. No systematic variation of K_2O and Na_2O occurs across the Atlanta lobe. These chemical variations correspond directly to modal variations. Tonalite occurs on the west and east margins, whereas the core of the batholith is biotite granodiorite transitional with muscovite-biotite granite.

GEOCHEMICAL CHARACTERISTICS OF THE VAN HORN PEAK CAULDRON COMPLEX

Intrusive and extrusive calc-alkaline rocks of the Eocene Challis Volcanics, as exposed in the Van Horn Peak cauldron complex (fig. 1), range from andesite to rhyolite and have been subjected to a variety of post-consolidation alteration processes. Back (1982) used petrologic and geochemical analyses to document similarities and differences between rock units and to determine the nature and extent of alteration. Rock samples were collected from three areas, both within and outside the caldera proper, and analyzed for 21 elements by semiquantitative direct-current arc spectroscopy and by energy-dispersive X-ray fluorescence spectrometry.

Early volcanic activity was mostly nonexplosive eruption of mafic to intermediate flows. Later volcanic activity was explosive and resulted in formation of calderas, grabens, and thick sections of intermediate to silicic tuff. Back found that successive tuffs are generally increasingly silicic, suggesting continued introduction of silica into the magma. The latest activity was intrusion of intermediate to silicic dikes and plugs. Late dikes generally have lower potassium and rubidium, and higher titanium, zirconium, and niobium, than older flows with similar silica contents.

Back recognized propylitic alteration throughout the study areas. Most units contain secondary calcite, chlorite, and sericite. Lesser amounts of quartz, sphene, potassium feldspar, and clay are also common. Zeolites occur in mafic to intermediate intrusive rocks in one area, fluorite occurs in two areas, and celadonite in one area. All occur along fractures and in vugs. Back concluded that these are products of low-temperature hydrothermal alteration and thus recognized at least two episodes of alteration. Propylitic alteration occurred first throughout the cauldron complex and was followed locally by cooler hydrothermal alteration.

ROCK GEOCHEMISTRY OF TERTIARY PLUTONIC ROCKS

Tertiary (Eocene) plutonic rocks of the Challis quadrangle comprise a bimodal suite of pink biotite granite and gray hornblende-bearing diorite. SiO_2 content of pink granite is 71-78 percent, K_2O averages about 4.8 percent, CaO is 1.7 percent or less, and MgO is <.5 percent (table 3 and K.M. Johnson, unpub. data). The dioritic rocks have variable SiO_2 contents and are high in CaO and MgO (Lewis and others, 1985). Trace-element analyses of pink granite show Rb:Sr ratios ranging from 400:1 to 1:8 (K.M. Johnson, unpub. data). The pink granite has some characteristics of A-type granitoids. Continuing work is directed at determining the relation between both types of plutonic rocks and the intrusive and extrusive rocks of the Challis Volcanics.

CHEMICAL CHARACTERISTICS OF THE GOLDEN SUNBEAM MINE AREA

Golden Sunbeam mine (pl. 1) is a disseminated gold-silver deposit in a rhyolite dome of the Challis Volcanic Group. The rhyolite intrudes rhyolitic to andesitic volcanic and volcaniclastic rocks, also of the Challis Volcanic Group. A cross-section of these rocks, as well as Cretaceous rocks and Paleozoic basement rocks, is exposed in the area from Golden Sunbeam mine north to the drainages of Mystery Creek (44°30′N, 114°49′W) and China Creek (44°24′N, 114°46′W). Foster and Cooley (1982) present semiquantitative spectrographic analyses of 127 rock samples from the area north of the mine. Their data show 13 rock types variably enriched in some or none of the 30 elements reported. Johnson and McIntyre (1983) report that rocks at Golden

Sunbeam mine are pervasively altered and contain anomalous concentrations of gold, silver, arsenic, molybdenum, zirconium, fluorine, and chlorine. These data were used in the assessment of the potential for similar deposits elsewhere in the Challis quadrangle (Johnson and Fisher, this volume, p. 163).

GOLD AND MOLYBDENUM IN DOUGLAS-FIR AND BEARGRASS

Exploration targets for gold, molybdenum, and tungsten have been identified at Red Mountain (45°00′N, 115°27′ W), Yellow Pine district, using biogeochemical techniques (Leonard and Erdman, 1983; Erdman and others, 1983, 1985). The area had been prospected for gold and silver for over 50 years with little success when the biogeochemical study was undertaken to assess the mineral potential of the area around the known stockwork. Wood of douglas-fir (*Pseudotsuga menziesii*) and leaves of beargrass (*Xerophyllum tenax*) were sampled because they concentrate gold and molybdenum, respectively.

The Red Mountain stockwork is a fine-scale stockwork, cut by small radial dikes, and locally dissected by radial faults. Host rocks are granitic rocks of the Cretaceous Idaho batholith, variably deformed and altered. The stockwork shows molybdenite, scheelite, and stibnite, in addition to sparsely disseminated pyrrhotite and ubiquitous pyrite and arsenopyrite. It is surrounded by a large envelope of clay alteration.

Soil and plant samples were collected on 600-ft centers over an area of 3,300 ft x 7,500 ft. Metal anomalies in the soils sampled were mostly weak and small, although a tungsten anomaly was located south of the stockwork. Metals in plant ash showed strong anomalies and large associated areas of above-median values. Most of these anomalies occur outside the stockwork, on either Quaternary valley fill or granodiorite containing inclusions of quartzite, biotite schist, and amphibolite. Analysis of ashed douglas-fir wood by instrumental neutron activation yielded gold values of 0.07-14.2 ppm. The most anomalous values (>4 ppm) are concentrated in the southern quarter of the grid area, where no anomalous gold was found in soils. Beargrass samples, which typically contain 20 ppm molybdenum, contained <5 to >500 ppm. A long continuous belt of above-median values of molybdenum suggests an extensive bedrock source. Geomagnetic data confirm the presence of an oval structure discordant with mapped bedrock structure.

URANIUM IN SPRING WATER AND BRYOPHYTES

Uranium occurs with vitrainized carbon fragments in arkosic sandstones and conglomerates of Eocene age at Basin Creek (44°17′N, 114°52′W), 6 mi northeast of Stanley. Springs are common at the contacts of rock units and support abundant growths of bryophytes, mostly mosses. Shacklette and Erdman (1982) measured uranium contents of spring water and bryophytes at 22 locations to determine which was the better indicator of uranium-bearing rock. Direct analysis of uranium in spring waters is often unsatisfactory because uranium commonly occurs at concentration levels near the sensitivity limit of the analytical method used and because fluctuations in flow rates of streams strongly affect uranium concentrations. Bryophytes are known to concentrate many elements in excess of concentrations in their substrates; also, because many bryophytes are perennial, they have the potential to integrate fluctuating uranium levels.

At each location, total gamma radiation was measured, spring water was sampled, and a single species of bryophyte was collected. Total gamma radiation values were not high and showed no consistent relation to uranium levels in spring water and bryophytes. Uranium in water and bryophyte samples was analyzed in the laboratory with a Scitrex UA-3 uranium analyzer. Measured values of uranium in water were normalized, using measured conductivity values, to account for dissolved solid content of the water. Values of uranium measured in bryophyte ash were normalized to account for contamination by trapped sediments. Three sites had anomalous normalized uranium values, both in water and in bryophytes. Shacklette and Erdman conclude that, at these springs, water and moss were equally useful in indicating uranium in buried rocks drained by the springs. However, bryophytes at all springs had higher concentrations of uranium than the waters in which they grew and the contrast between background and anomalous levels was greater in bryophytes than in water. In addition, normalization procedures were necessary for recognition of anomalies in water, whereas anomalies in bryophytes were recognizable without normalization. No significant differences were noted between bryophyte species; Shacklette and Erdman state that ". . . in sampling mosses as biogeochemical indicators, species identification probably can be disregarded."

COPPER AND COBALT IN AQUATIC MOSSES AND STREAM SEDIMENTS

Erdman and Modreski (1984) report that prospecting for copper and cobalt can be done successfully with aquatic mosses, which is of particular value in areas where steep terrain and attendant high flow rate of streams make it difficult to obtain adequate sediment samples. They collected samples of aquatic mosses and associated stream sediments across several mineralized zones in the drainage of North Fork of Iron Creek (44°58′N, 114°07′W) at the southeasternmost extension of the 30-mi-long Idaho cobalt belt.

Sediment samples were analyzed by inductively coupled plasma emission spectrometry and yielded copper values of 15-1,000 μg/g (ppm) and cobalt values of 9-320 μg/g. Aquatic moss samples, analyzed by atomic absorption spectrophotometry, yielded copper values of 190-35,000 μg/g and cobalt values of 45-2,000 μg/g. For both copper and cobalt the metal content of mosses correlates almost perfectly ($r=0.95$ and 0.93, respectively) with metal content of stream sediments. However, the differences between background and anomalous values in mosses are considerably greater than the differences in stream sediments. Background concentrations are 20 μg/g for copper in sediments, 200-300 μg/g for copper in moss, 10-15 μg/g for cobalt in sediments, and 50 μg/g for cobalt in moss.

In addition, Erdman and Modreski report that for copper and cobalt the effects of mineralization on the metal content of mosses override the possible effects of differences between moss species. They collected only one species at each sample site and found that they had both similar concentrations between species and large differences within the same species depending on whether or not the sample was downstream from mineralized ground. This suggests that mosses as a group are reliable accumulators of copper and cobalt and that the sampler need not be concerned with species identification or even with collection of only a single species.

MINERAL RESOURCES

By Frederick S. Fisher

ORE DEPOSIT TYPES

Ore deposits in the Challis quadrangle may be classified as shown on table 1. This classification was designed to facilitate the mineral resource assessment of the quadrangle and is not an attempt to group the deposits solely by genesis or by descriptive criteria. The classification is specific to the Challis quadrangle; it will apply to ore deposits outside the quadrangle only as far as the recognition criteria for each deposit type can still be considered valid. No attempt was made to make the classification of ore deposits compatible with any other more general classification scheme.

Each of the ore deposit types shown on table 1 is described and its resource potential discussed later in this report. Examples of each of these ore deposit types are also given in the mineral resource assessments.

Vein deposits of diverse types are widespread throughout the Challis quadrangle and occur in all bedrock geologic environments. Exploration and development of the vein deposits, especially the precious-metal veins, has been the major historic mining objective in the area and still attracts considerable attention, particularly from individuals and smaller mining companies. Veins have also yielded significant amounts of tungsten, antimony, and gold from deposits near Yellow Pine.

Stockwork deposits are known to be present in all but the carbonate rock and alluvial deposit terranes. Molybdenum is currently (1985) being mined from large stockwork deposits at Thompson Creek (pl. 1); if the present production continues, this will be in a few years the most valuable commodity produced from the Challis quadrangle. Several of the larger precious-metal veins, especially in the Yankee Fork district, have associated stockworks that are being explored for their precious-metal content. Stockworks in high-level rhyolites offer attractive targets for large-tonnage, low-grade precious metal deposits.

Pegmatites and miarolitic cavity deposits are restricted to the Idaho batholith and Tertiary plutonic rock terranes. These deposits are not large producers and are of greater mineralogical interest than as producers of bulk ores. Pegmatites in the Challis quadrangle have been prospected mainly for their content of mica, columbite, and piezoelectric quartz.

Skarns occur only in the black shale terrane near intrusive bodies, and in roof pendants in the Idaho batholith terrane. Polymetallic skarns in roof pendants are of interest mostly because of their tungsten content. Skarns in the black shale terrane contain both tungsten and large deposits of molybdenum.

Some of the largest producers of precious and base metals from the Challis quadrangle have been irregular replacement deposits, in particular those in the carbonate rock terrane. Irregular replacements of mercury are present in Precambrian rocks near Yellow Pine and zeolite replacements are widespread in volcanic rocks within the Twin Peaks caldera.

Stratiform replacements occur in the carbonate rock, black shale, and Challis volcanic rock terranes. Gold deposits in the Thunder Mountain caldera (Challis volcanic rock terrane) have been mined sporadically for many years, and replacement deposits in the carbonate rock terrane near Bayhorse contain large resources of fluorspar.

Stratabound syngenetic deposits are restricted to two terranes. Vanadium and base- and precious-metal deposits occur in the black shale terrane, and cobalt-copper deposits in the Precambrian rock terrane. Little or no production has been recorded from these deposits in the Challis quadrangle, but they may contain very large, low-grade resources of lead, zinc, vanadium, and silver.

Placer deposits of gold and radioactive black sands are common in the alluvial terrane. Gold placers were mined as early as the 1860's within the quadrangle and have yielded over 132,300 oz to date. Black-sand placers have produced chiefly euxenite and monazite. Some of the largest resources of monazite in the United States are present in the black-sand placers of Long Valley (44°29′ N., 116°00′ W.) and Bear Valley (44°22′ N., 115°24′ W.).

METAL PRODUCTION AND DISTRIBUTION PATTERNS

Total production of gold, silver, copper, lead, and zinc from individual lode mines in the Challis quadrangle is given by mine, mining district, and county in table 9. Table 10 lists the recorded post-1900 placer production of gold and silver. The pre-1901 placer production of gold is estimated on table 11. These data are at best estimates, because much of the pre-1901 production was not recorded and in general these production figures are probably low.

Figures 15 and 16 summarize the data from table 9. Figure 15 shows the production of gold, silver, copper, lead, and zinc for six lithologic terranes in the Challis quadrangle. Production figures are plotted on a logarithmic scale, and the total amount produced is shown by the value at the top of each column. Figure 16 shows histograms of the percentages of precious and base metals produced from the six lithologic terranes. Deposits hosted by the Idaho batholith terrane have produced by far the greatest amount of gold followed in order by those hosted by the Challis volcanic rock terrane and the Precambrian rock terrane. Forty percent of the total lode gold produced from the quadrangle has come from the Yellow Pine and Meadow Creek mines in the Yellow Pine district.

The production of silver shows a somewhat different pattern than that of gold (figs. 15 and 16). Mines within Paleozoic sedimentary rocks, the black shale and carbonate rock terranes, have produced the bulk of the silver from the quadrangle. The combined total of the igneous rock terranes (Idaho batholith, Challis volcanic rock, and Eocene plutonic rock terranes) is about one quarter of the amount of silver produced from deposits hosted by Paleozoic rocks. Production figures thus suggest that gold and lesser amounts of silver are associated with igneous rock terranes and silver and lesser amounts of gold are associated with the Paleozoic sedimentary rocks.

Production data for copper, lead, and zinc from the main geologic provinces in the quadrangle are also shown on figures 15 and 16. Values listed for zinc are probably biased to the low side because in the early years of this century mines were penalized for ore containing zinc. Thus much zinc-rich ore was not shipped or recorded. Several patterns are obvious: first, the greatest production of base metals has come from mines in terranes containing sedimentary rocks (carbonate rock and black shale terranes); second, more copper has been produced from the black shale terrane and more lead from the carbonate terrane; and third, production of base metals from the Eocene plutonic and Challis volcanic rock terranes is insignificant. It should be noted that most of the lead and nearly all of the zinc shown from the Idaho batholith terrane was produced from a single mine, the Deadwood/Hall-Interstate mine. Ore at this mine occurs as veins in roof

Table 9.--Production of precious and base metals from the Challis quadrangle

[Data from unpublished records of U.S. Bureau of Mines, Spokane, Wash., and from Anderson (1949, 1953), Anderson and Rasor (1934), Cater and others (1973), Choate (1962), Ross (1930, 1934b, 1937), Treves and Melear (1953), Tschanz and others (1974), and Umpleby (1913a, 1913b). --, no data]

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
BOISE COUNTY					
BANNER DISTRICT					
Banner Group	45	47,899	465	317	--
Choowathoo	8	5	--	--	--
Granite 1 & 2	2	1	--	--	--
James Mill	1	1	--	--	--
McKinley	1	9	--	--	--
Sego Lily	6	3	--	--	--
Unknown	28	990	--	34	--
TOTAL	91	48,908	465	351	--
GRIMES PASS DISTRICT					
Baby	45	18	--	--	--
Black Jack	156	92	--	--	--
Bruser	66	472	249	2,457	--
Comeback	11,840	343,374	17,020	152,886	1,583
Coon Dog	734	7,892	26,737	104,762	11,735
El Oro	1	157	--	27,393	11,000
Enterprise	255	2,427	11,031	51,419	--
Gold Belt	206	107	--	--	--
Golden Age	9,936	20,842	9,402	38,441	--
Golden Chariot	1,267	614	--	--	--
Golden Cycle	1,664	1,016	--	--	--
Grand View (or Buckhorn)	172	238	--	100	--
Grimes Pass		498	204	566	--
Independence	158	632	--	4,536	--
J & S	284	128	--	--	--
KC Group	348	719	47	227	--
Missouri	116	9,140	462	20,527	1,944
Mohawk	78	1,124	715	30,202	--
Mountain Queen	27	1,294	680	1,559	--
San Cristobal	103	43	--	--	--
Silver Gem	65	5,268	4,237	3,497	--
Sloper	730	319	--	--	--
Smuggler	1,918	14,546	5,484	386,410	--
TOTAL	30,169	410,960	76,268	824,982	26,262

Table 9.--Production of precious and base metals from the Challis quadrangle--Continued

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
PIONEERVILLE DISTRICT					
Mammouth	576	263	--	--	--
TOTAL	576	263	--	--	--
NORTH OF BANNER DISTRICT					
Idaho-Birthday	821	657	472	1,625	--
Magnolia (Miller Mtn.)	89	20	--	--	--
Specimen	295	88	--	--	--
TOTAL	1,205	765	472	1,625	--
COUNTY TOTAL	32,041	460,896	77,205	826,958	26,262
CUSTER COUNTY					
BOULDER CREEK DISTRICT					
Hoodoo	35	168,552	6,250	160,535	9,133,188
Idaho-Custer	7	3,166	400	60,500	131,500
Little Livingston	1	709	--	5,700	--
Livingston	54	177,410	6,808	276,862	9,268,978
TOTAL	97	349,837	13,458	503,597	18,533,666
BAYHORSE DISTRICT					
Aetna (Riverview)	--	4,472	--	47,428	--
Bayhorse Mines Group	11	34,231	18,200	196,600	13,000
Beardsley	--	1,500,000	--	30,000,000	--
Big Ben	--	101	1,632	325	--
Billour & Turtle	--	1,147	--	13,594	--
Blue Bird-Silver Bar	--	17	--	484	--
Blue Point	--	10	76	15	--
Burton	--	18	--	626	--
Cave	1	2,338	666	29,767	--
Cemetery	1	2,429	2,732	--	--
Challis View	--	200	41	942	--
Clarence	1	3	500	--	--
Clayton Silver	2,284	6,623,802	1,413,977	83,491,094	27,524,425
Clayton View	--	1,087	143	53,091	--
Companion Group	2	--	--	--	--
Compass	--	639	--	13,473	--
Daugherty Group	--	34	--	854	--
Democrat & Vermont	1	1,591	1,200	12,044	--

Table 9.--Production of precious and base metals from the Challis quadrangle--Continued

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
Deltafee	--	219	41	5,927	--
Dry Hollow	1	405	70	10,310	--
Dryden	3	27,297	1,797	339,467	630,748
Ella	22	67,807	10,000	954,775	--
Ellis Croup	--	792	--	23,045	400
Eight	1	49	60	139	--
Estes Gold	20	4,246	800	300	200
Eureka	--	177	--	15,584	--
Excelsior Lease	1	607	227	4,612	2,960
Fisher	1	39	--	1,057	--
Fisher & Argyle	--	48	--	1,189	--
Fisher-Boorn	75	160	--	--	--
Forest Rose	1	6,623	927	123,696	--
Garden Creek	--	20	--	562	--
Garden Creek Silver	--	13	--	382	--
Good Friend Group	--	5,092	1,939	15,639	--
Grandview	--	137	178	--	--
Grizzley-Zodiac-Democrat	2	5,133	1,058	55,735	--
Henze	--	240	--	9,585	--
Hermit	2	1,046	--	9,284	--
Homestake Group (Last Chance)	1	4,806	1,731	90,901	--
Hoosier	--	433	--	5,401	--
Horseshoe	--	351	395	16,941	3,956
Japan & Mary	--	607	217	9,703	--
Jarvis	1	98	10	1,980	--
Juanita	--	145	--	800	100
Katherine	--	867	746	31,239	--
Last Chance (Homestake)	1	2,092	697	29,399	50
Lost Eagle	3	315	--	3,240	--
Lucky Strike	--	60	38	--	--
Lucky Thirteen	1	183	--	4,184	--
Maryland & Centennial	--	99	116	188	--
Pacific	17	30,307	3,150	393,216	--
Ramshorn	145	2,101,962	926,609	5,688,604	23,200
Red Bird	229	680,330	64,641	16,578,567	38,056
Red Top	--	267	70	9,295	100
Riverview	19	40,288	33,198	443,932	82,309
Rob Roy	--	1,694	766	87,444	--
Rose Bud	--	23	--	50	--
Salmon River	83	141,053	32,813	1,709,834	359,166
Saturday & Mollie D	12	3,737	741	129,138	29,485
Saturday Mountain Group	--	17	--	600	200
Shamrock	--	21	300	--	--
Silver Bell	1	1,627	1,526	5,965	72
Silver Brick	--	4,264	--	27,040	--
Silver Leaf	1	132	33	930	--
Silver Rule	1	1,841	749	19,632	1,507

Table 9.--Production of precious and base metals from the Challis quadrangle--Continued

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
Skylark	1	2,616,000	5,623,000	--	--
Skyline	--	250	77	7,204	--
Snowstorm	2	1	--	--	--
South Butte	21	70,850	2,578	1,741,280	1,098
St. Joe	--	164	--	4,405	2,105
Sunshine	1	312	78	622	--
Sure Shot	--	36	--	816	--
Swallow	1	8	--	--	--
Turtle	3	26,936	10,739	278,048	3,116
Turtleback	--	129	111	1,137	--
Twin Apex	--	271	200	249,045	3,000
Woodtick	--	82	61	708	--
Young Copper	2	160	--	3,100	--
Zodiac	--	73	--	1,314	577
Unknown (13 properties)	--	6,093	6,696	53,146	--
TOTAL	2,976	14,031,253	8,168,350	143,060,673	28,719,830
EAST FORK DISTRICT					
Confidence	1	353	33	1,322	--
Deer Trail	--	6,070	--	9,500	7,900
FDR	--	434	--	16,751	--
TOTAL	1	6,857	33	27,573	7,900
STANLEY & STANLEY BASIN					
Accidental	4	10	--	--	--
Big Casino-Little Casino	3	6	--	--	--
Blackjack	--	53	--	800	200
Charm	21	8	--	--	--
Dudley	26	3	--	--	--
Dukes Mixture	60	100	--	--	--
Fort Pitt et al	43	41	--	--	--
Gold Chance	290	--	--	--	--
Golden Day	7	45	--	--	--
Hecla & Hercules	3	1	--	--	--
Homestake	35	50	--	--	--
Lucky Strike	5	7	--	--	--
Mountain Girl	46	113	235	4,066	--
Pierce	8	13	--	--	--
Progressive	7	2	--	--	--
Stanley	41	17	--	--	--
Valley Creek Group	780	646	--	--	--
Valley Creek No. 1,2,& 3	813	33,249	1,876	113,721	924
Unknown	1	165	--	--	--
TOTAL	2,193	34,529	2,111	118,587	1,124

Table 9.--Production of precious and base metals from the Challis quadrangle--Continued

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
SHEEP MOUNTAIN DISTRICT					
Wauda	1	480	--	11,400	--
Other production (1958-60)	--	48	5	1,188	--
TOTAL	1	528	5	12,588	--
LOON CREEK DISTRICT					
Cash Box Group	27	--	--	--	--
Lost Packer	19,790	48,451	1,797,786	--	--
Sunrise Group	--	417	--	8,038	--
Other production (1934-48)	36	14	100	--	--
TOTAL	19,853	48,882	1,797,886	8,038	--
SEAFOAM DISTRICT					
Greyhound Mine	42	13,148	682	10,865	45,511
Josephus Lake	51	5,640	--	12,560	--
Mountain King Mine	159	60,534	12,744	728,222	758,260
Seafoam and Silver King	210	1,560	435	11,243	16,000
Other production (1910-65)	190	17,863	4,486	162,624	29,435
TOTAL	652	98,745	18,347	925,514	849,206
UNCERTAIN DISTRICTS					
U.S. Lead	12	2,516	2,171	60,248	3,298,738
Unknown (R. Leach, Sunbeam)	--	24	--	200	--
TOTAL	12	2,540	2,171	60,448	3,298,738
YANKEE FORK DISTRICT					
Alpine	1	1	--	--	--
Altura	12	1,277	--	--	--
American Dollar	1	83	--	--	--
Arcade	8	1,194	--	--	--
B & M	22	1,804	200	--	--
Bachelor Mountain	383	624	--	--	--
Badger Group	102	5,765	--	--	--
Bimetallic	14	453	100	81	--
Bismark	17,943	21,288	--	--	--

Table 9.--Production of precious and base metals from the Challis quadrangle--Continued

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
Black Man	--	7	--	--	--
Buster	6	379	20	23	--
Casey	1	194	--	--	--
Charles Dickens	78	423	3	--	--
Copper Lode	9	309	120	--	--
Corey	4	1	--	--	--
Custer Slide	177	1,143	5	320	--
Dead Soldier	6	83	--	--	--
Dubuque	4	179	126	--	--
Estes Mountain	16	1,002	100	100	--
Eustace Mountain	23	1,239	160	258	--
Fair Play	8	624	--	--	--
Gold Star	3	--	--	--	--
Golden Eagle	1	4	--	--	--
Gopher	3	175	--	--	--
Harry Ann	--	96	369	4,258	1,711
Hidden Treasure	41	263	19	18	--
Homestake	1	212	--	--	--
Ideal No. 1	1	--	--	--	--
Joker	8	3	--	--	--
Jordan	173	4,492	--	--	--
Julietta	87	105	--	--	--
Kirkland	3	702	140	30	--
Kwajalein	--	90	1,155	648	--
Last Chance	30	7	--	--	--
Letha	1	61	--	--	--
Longview	47	--	--	--	--
Lost & Found	2	7	--	--	--
Lucky Boy	17,502	302,001	166	93	--
Lucky Day	11	7	--	--	--
Lucky Strike	1	1	--	--	--
Lynch-Day	7	45	--	447	--
McFadden	39	5,902	774	6,900	--
Montana Group	1,963	18,706	--	--	--
Monte Carlo	1	158	85	1,054	--
Monte Cristo	1	39	--	--	--
Mountain King	7	1,732	--	23,251	--
Mulcahy	7	957	--	--	--
New Light	17	19	--	--	--
Peak	1,224	4,450	710	64	--
Pilot Extension	11	397	49	155	--
Pocket Nos. 1-3	7	264	--	--	--
Rankin Gulch	4	71	--	1,707	--
Runover	89	49	--	--	--
Silver Queen	6	486	89	2,574	--
Silver Star	--	162	335	1,655	--
Snowdrift	175	1,473	159	71	--

Table 9.--Production of precious and base metals from the Challis quadrangle--Continued

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
Sunbeam	217	2,490	--	--	--
Sunset	5	4	--	--	--
Tonto Page	3	301	65	30	--
Unknown	225	1,181	215	1,383	--
Valley Creek	3	1	--	--	--
Walters	2	--	--	--	--
Washington	1	87	--	262	--
Whynot	820	34,896	12,492	15,387	--
Yankee Fork	83	13,101	1,670	1,144	--
RECORDED TOTAL	41,650	433,269	19,326	61,913	1,711
CALCULATED(PRE 1900)TOTAL	240,000	8,674,700	--	--	--
GRAND TOTAL	281,650	9,107,969	19,326	61,913	1,711
COUNTY TOTAL	307,435	23,681,140	10,021,687	144,778,931	51,412,175
LEMHI COUNTY					
GRAVEL RANGE DISTRICT					
Allison Mine	2	184	--	--	--
Rabbit Foot Mine	116	136	--	--	--
Silver Creek Mine	87	188	--	--	--
Singheiser Mine	317	8,415	2,543	--	--
TOTAL	522	8,923	2,543	--	--
PARKER MOUNTAIN DISTRICT					
Ed Williams (White Rock)	216	776	--	--	--
Parker Mine (Pitch Hit)	603	3,744	--	--	--
TOTAL	819	4,520	--	--	--
YELLOWJACKET DISTRICT					
Black Eagle Mine	78	93	--	--	--
Bryan Mine	377	137	3,551	1,541	--
Clark-Murray Mine	1	--	--	--	--
Columbia Mine	1	367	641	--	--
Comeback Mine	--	23	--	--	--
Copper Glance Group	6	344	3,516	1,171	--
Diamond Queen & Mayflower	2	3	--	--	--
Grup Staple Mine	4	1	--	--	--
Idaho Yellowjacket	39	12	--	--	--

Table 9.--Production of precious and base metals from the Challis quadrangle--Continued

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
Lead Star Mine	3	803	760	9,639	--
Mayfield Mine	2	--	--	--	--
Merritt Mine	2	--	--	--	--
Moss Mine	1	1	283	--	--
Northstar Group	6	2	60	--	--
Silver Moon (Liberty)	4	1,244	169	4,106	4,015
Steen Group	67	234	8,220	--	--
Tin Cup Mine	136	111	3,977	108	--
Yellowjacket Mine	2,972	3,440	4,402	7,650	100
Yellowjacket Tailings	33	7	--	--	--
Other production (1934-48)	--	98	3,375	--	--
RECORDED TOTAL	3,734	6,920	28,954	24,215	4,115
CALCULATED (PRE 1900)	21,770	--	--	--	--
GRAND TOTAL	25,504	6,920	28,954	24,215	4,115
COUNTY TOTAL	26,845	20,363	31,497	24,215	4,115
VALLEY COUNTY					
DEADWOOD BASIN DISTRICT					
Daisy King	--	75	--	--	--
Deadwood	3	647	516	5,814	1,270
Unknown (Lee Bunchm,Boise)	7	4	--	--	--
Jumbo Group	27	11	--	--	--
Kimball	3	9	--	--	--
Long Chance	29	16	--	--	--
Lost Pilgrim (Hall-Inter.)	2,660	643,526	444,207	4,973,645	10,175,563
Mary Jane	12	6	--	--	--
Mary Blue & Union	3,104	1,333	19	99	--
Mulligan	2	1	--	--	--
Ranger	6	49	--	465	--
Rolling Stone	--	27	--	--	--
W-J-L	17	41	77	--	--
Other production (1936-41)	40	1	--	--	--
TOTAL	5,910	645,746	444,819	4,980,023	10,176,833

Table 9.--Production of precious and base metals from the Challis quadrangle--Continued

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
PISTOL CREEK DISTRICT					
Cougar Group	183	483	--	341	--
Lucky Lad	1,309	24,165	2,897	332,716	--
TOTAL	1,492	24,648	2,897	333,057	--
THUNDER MOUNTAIN DISTRICT					
Dewey (Golden Reef)	14,381	8,612	--	--	--
Hancock Group	22	19	--	--	--
Iron Clad	1	9	--	--	--
Sunnyside	5,237	3,909	--	--	--
Unknown (4 properties)	45	53	223	--	--
Other production (1938-40)	--	319	--	--	--
TOTAL	19,686	12,921	223	--	--
WARM LAKE DISTRICT					
Trapper Flat	23	34	--	--	--
TOTAL	23	34	--	--	--
YELLOW PINE DISTRICT					
B-B	4	298	--	--	--
Fern Group	2	17	--	--	--
Metalore	--	38	250	1,610	--
Oberbillig (Quartz Creek)	24	202	--	--	--
Silver Creek	--	325	--	--	--
West End	66,000	30,000	--	--	--
Yellow Pine/Meadow Creek	309,478	1,683,674	45,482	15,310	--
Other production (1936-46)	--	1,379	89	2,287	--
TOTAL	375,508	1,715,933	45,821	19,207	--
COUNTY TOTAL	402,619	2,399,282	493,760	5,332,287	10,176,833
QUADRANGLE TOTAL	768,940	26,561,681	10,624,149	150,962,391	61,619,385

Table 10.--Post-1900 placer gold and silver production

[Data from unpublished records of the U.S. Bureau of Mines and from Anderson (1953), Cater and others (1973), Choate (1962), Ross (1930, 1937b), Treves and Melear (1953), and Umpleby (1913a, 1913b)]

	Gold (oz)	Silver (oz)
Boise County		
District		
Grimes Pass	821.36	250.00
Banner	716.24	423.00
Boise Basin	401.79	123.00
Garden Valley/Lowman	246.50	39.00
Total	2,185.89	835.00
Custer County		
District		
Bayhorse	48.06	18.00
Seafoam	3.00	0.00
Rough Creek	74.40	10.00
Greyhound	25.34	7.00
Loon Creek	41.80	4.00
Yankee Fork	38,292.61	22,299.00
Stanley/Stanley Basin	6,642.34	2,800.00
Total	45,127.55	25,138.00
Lemhi County		
District		
Yellowjacket	233.21	23.00
Middle Fork Salmon River	18.30	3.00
Forney	962.67	603.00
Total	1,214.18	629.00
Valley County		
District		
Thunder Mountain	497.22	346.50
Bear Valley	120.00	64.00
Seafoam	1.83	0.00
Deadwood Basin	1,030.35	91.37
Middle Fork Salmon River	18.44	0.00
Gold Fork	9.00	1.00
Total	1,676.84	502.87
Challis quadrangle total	50,204.46	27,104.87

Table 11.--Pre-1901 production of placer gold from the Challis quadrangle

[Data from Cater and others (1973), Choate (1962), Umpleby (1913b), and Umpleby and Livingston (1920)]

	Dollars (reported)	Ounces Au (calculated)
Custer County		
District		
Loon Creek (Canyon Creek)	1,000,000	48,379
Robinson Bar (Centauras)	80,000	3,870
Robinson Bar (Great Centennial)	100,000	4,838
Stanley Basin (Big Casino Creek)	8,000	387
Stanley (Buckley Bar)	250,000	12,095
Stanley (Joe´s Gulch)	70,000	3,387
Stanley (Kelly Creek)	87,000	4,209
Yankee Fork (Jordan Creek)	50,000	2,419
Yankee Fork (Rough Creek)	15,000	726
Valley County		
District		
Thunder Mountain (Dewey)	40,000	1,935
Challis quadrangle total	1,700,000	82,245

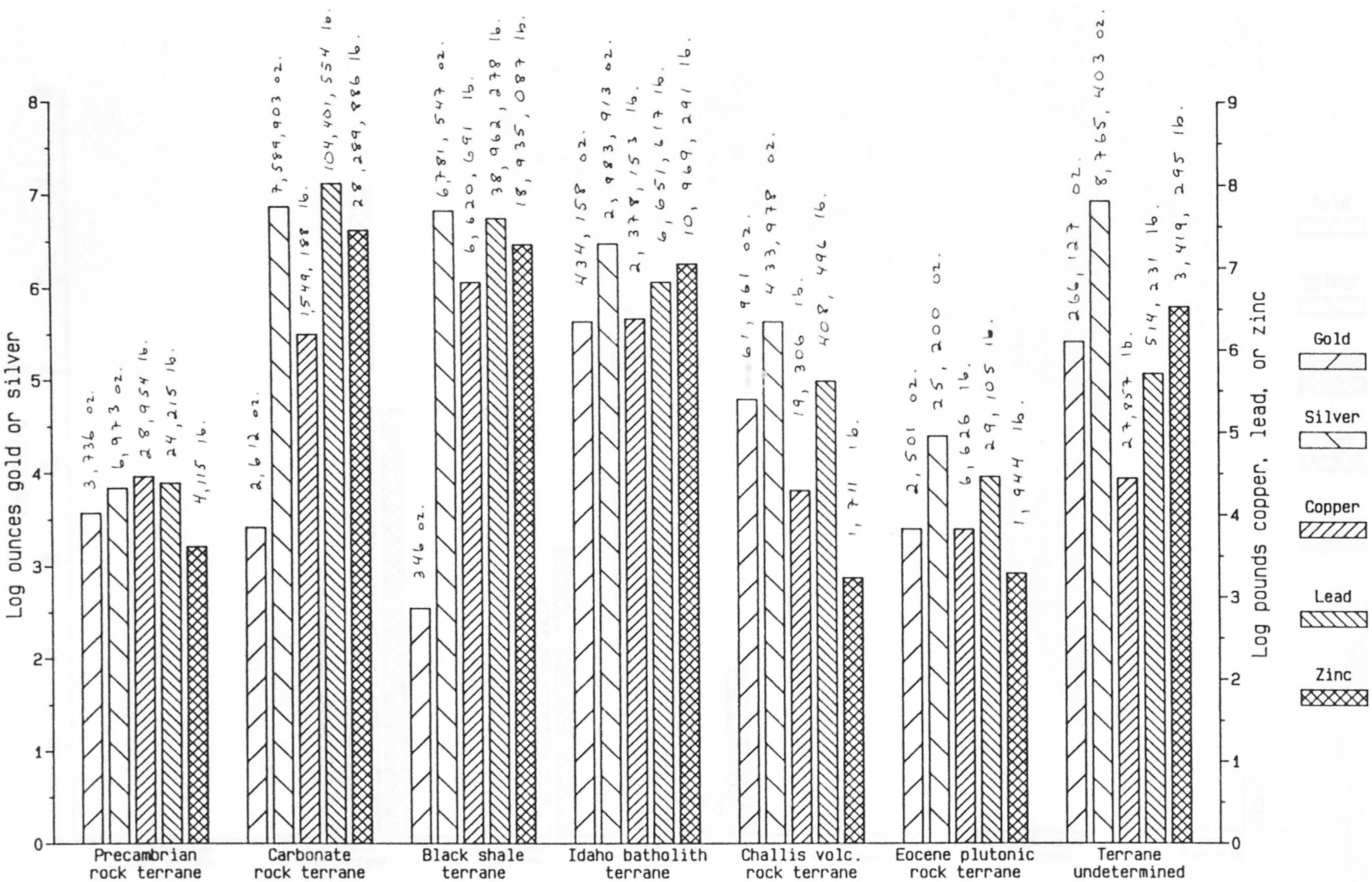


Figure 15. Histograms showing total amounts of base and precious metals produced from each lithologic terrane.

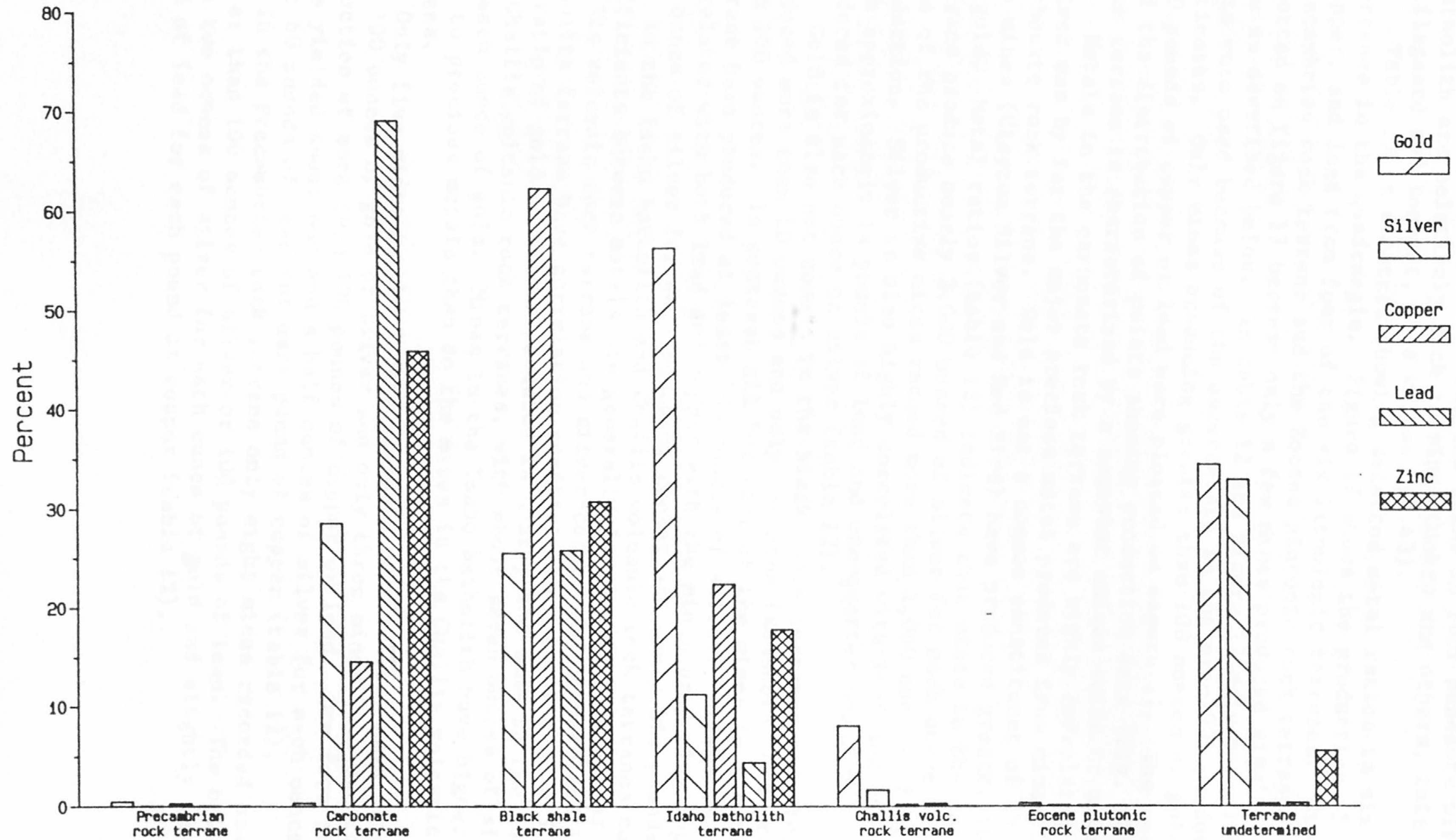


Figure 16. Histograms showing percentages of base and precious metals produced from lithologic terranes.

pendants of metamorphosed sedimentary rocks within the Idaho batholith. Ores produced from many of the skarns and veins in roof pendants within the Idaho batholith are relatively rich in zinc (Cookro and others, this volume, p. 172; Kiilsgaard and Bennett, this volume, p. 43).

Table 12 is a matrix showing selected metal ratios in six lithologic terranes in the quadrangle. Figure 17 shows the production of gold, silver, copper, and lead from four of the six lithologic terranes. Mines in the Precambrian rock terrane and the Eocene plutonic rock terranes were not plotted on figure 17 because only a few mines produced significant amounts of ore as described below. In table 12 and figure 17 only post-1900 production data were used because of the uncertainty in the pre-1901 production estimates. Only mines producing greater than 100 ounces of gold or silver or 100 pounds of copper or lead were plotted on figure 17. The ratios (table 12) and the distribution of points showing production data (fig. 17) suggest that each terrane is characterized by a somewhat unique suite of metals.

Metals in the carbonate rock terrane are highly correlated (fig. 17A). Silver was by far the major precious metal produced from mines in the carbonate rock terrane. Gold is not a common constituent of the ores; only two mines (Clayton Silver and Red Bird) have produced greater than 100 ounces of gold. Metal ratios (table 12) indicate that mines in the carbonate rock terrane produce nearly 3,000 ounces of silver for each ounce of gold. All but five of the productive mines record more than 1,000 ounces of silver production. Silver is also highly correlated with lead and copper (fig. 17A) with approximately 14 pounds of lead and one-quarter pound of copper being produced for each ounce of silver (table 12).

Gold is also not common in the black shale terrane; only four mines have produced more than 10 ounces and only one mine (Ramshorn) has produced greater than 100 ounces. In contrast all but four of the mines in the black shale terrane have produced at least 100 ounces of silver. Silver is highly correlated with both lead and copper with the mines producing approximately one ounce of silver for each pound of copper and every six pounds of lead.

In the Idaho batholith and Challis volcanic rock terranes correlation coefficients between metals are generally low. Only gold-silver in the Challis volcanic rock terrane and silver-copper and copper-lead in the Idaho batholith terrane have correlation coefficients greater than 0.5 (fig. 17B). The ratio of gold to silver produced is nearly the same in the Idaho batholith and Challis volcanic rock terranes, with about seven ounces of silver produced for each ounce of gold. Mines in the Idaho batholith have higher ratios of base to precious metals than do the mines in the Challis volcanic rock terrane.

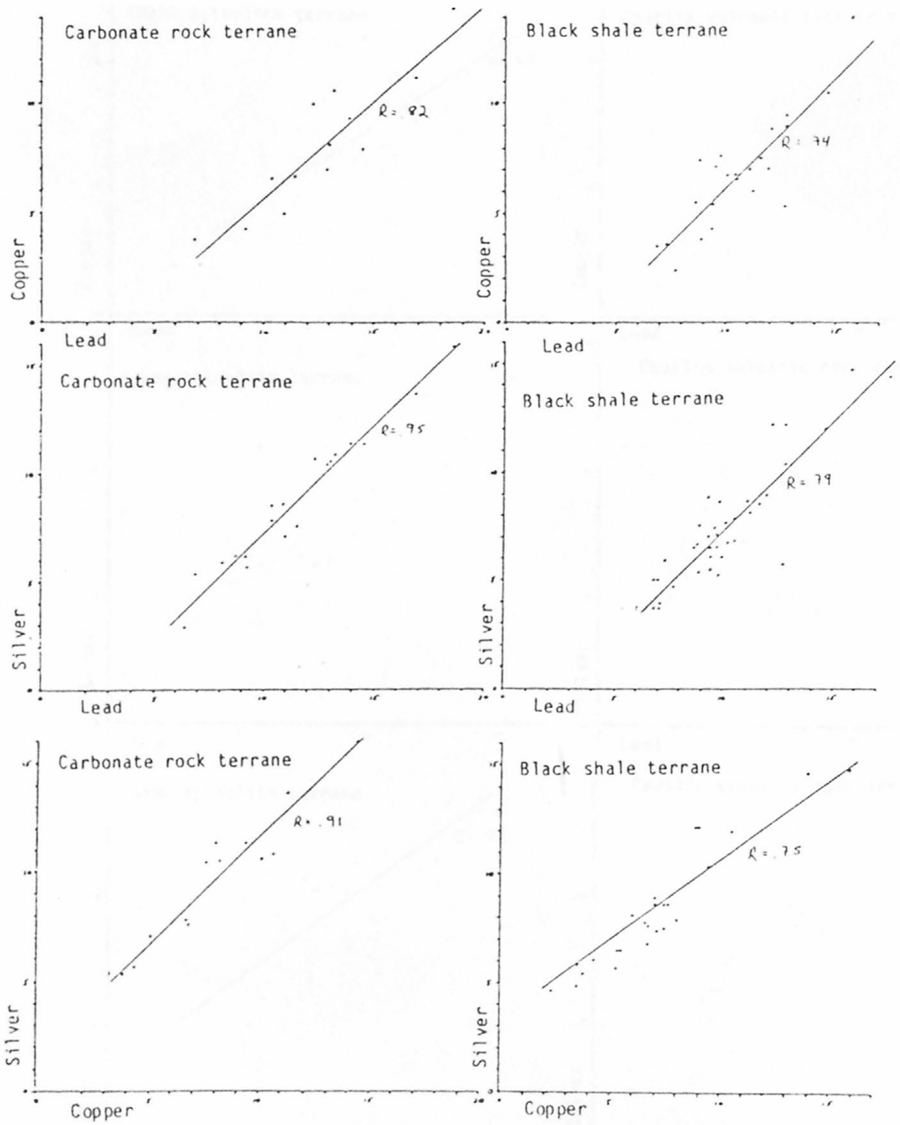
Only five mines in the Eocene plutonic rock terrane have produced greater than 100 ounces of gold or silver and only three mines have recorded a production of more than 100 pounds of copper or lead. Ore from the productive mines yielded about one and a half ounces of silver for each ounce of gold and about 60 pounds of lead for each pound of copper (table 12).

In the Precambrian rock terrane only eight mines recorded production of greater than 100 ounces of silver or 100 pounds of lead. The ores yielded about two ounces of silver for each ounce of gold and slightly less than one pound of lead for each pound of copper (table 12).

Table 12.--Selected metal ratios in ores produced from lithologic terranes in the Challis quadrangle

[Gold and silver in ounces; copper and lead in pounds]

	Precambrian rock terrane	Carbonate rock terrane	Black shale terrane	Idaho batholith terrane	Challis volcanic rock terrane	Eocene plutonic rock terrane
Au:Ag	1:1.9	1:2,905	1:19,599	1:6.9	1:7	1:1.4
Au:Cu	1:7.8	1:593	1:19,134	1:5.5	1:0.3	1:0.4
Au:Pb	1:6.5	1:39,969	1:112,607	1:15	1:0.5	1:22
Ag:Cu	1:4.2	1:0.2	1:0.97	1:0.79	1:0.04	1:0.26
Ag:Pb	1:3.5	1:14	1:5.7	1:2.2	1:0.07	1:16
Cu:Pb	1:0.84	1:67	1:5.8	1:2.7	1:1.5	1:61



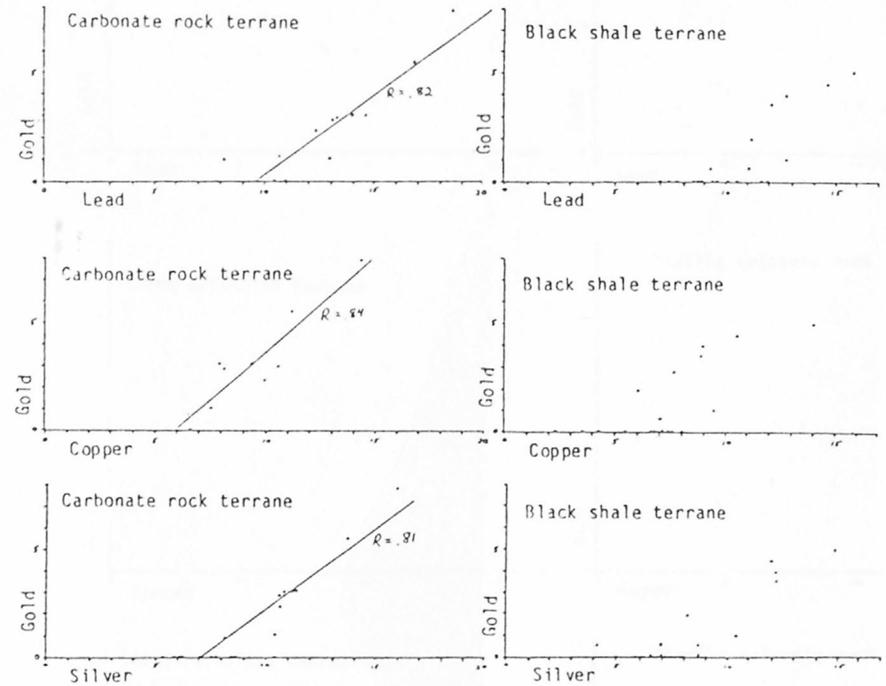


Figure 17A. Correlation diagrams for gold, silver, copper, and lead in the carbonate rock and black shale terranes. Values plotted are the natural logarithms of the total amount of metal produced from each mine in the two terranes. Gold and silver values are in ounces; copper and lead values are in pounds. Only mines that produced more than 100 ounces of gold or silver or 100 pounds of copper or lead were plotted. Least square regression lines were drawn only in those diagrams where the metals had a correlation coefficient (R) greater than 0.5.

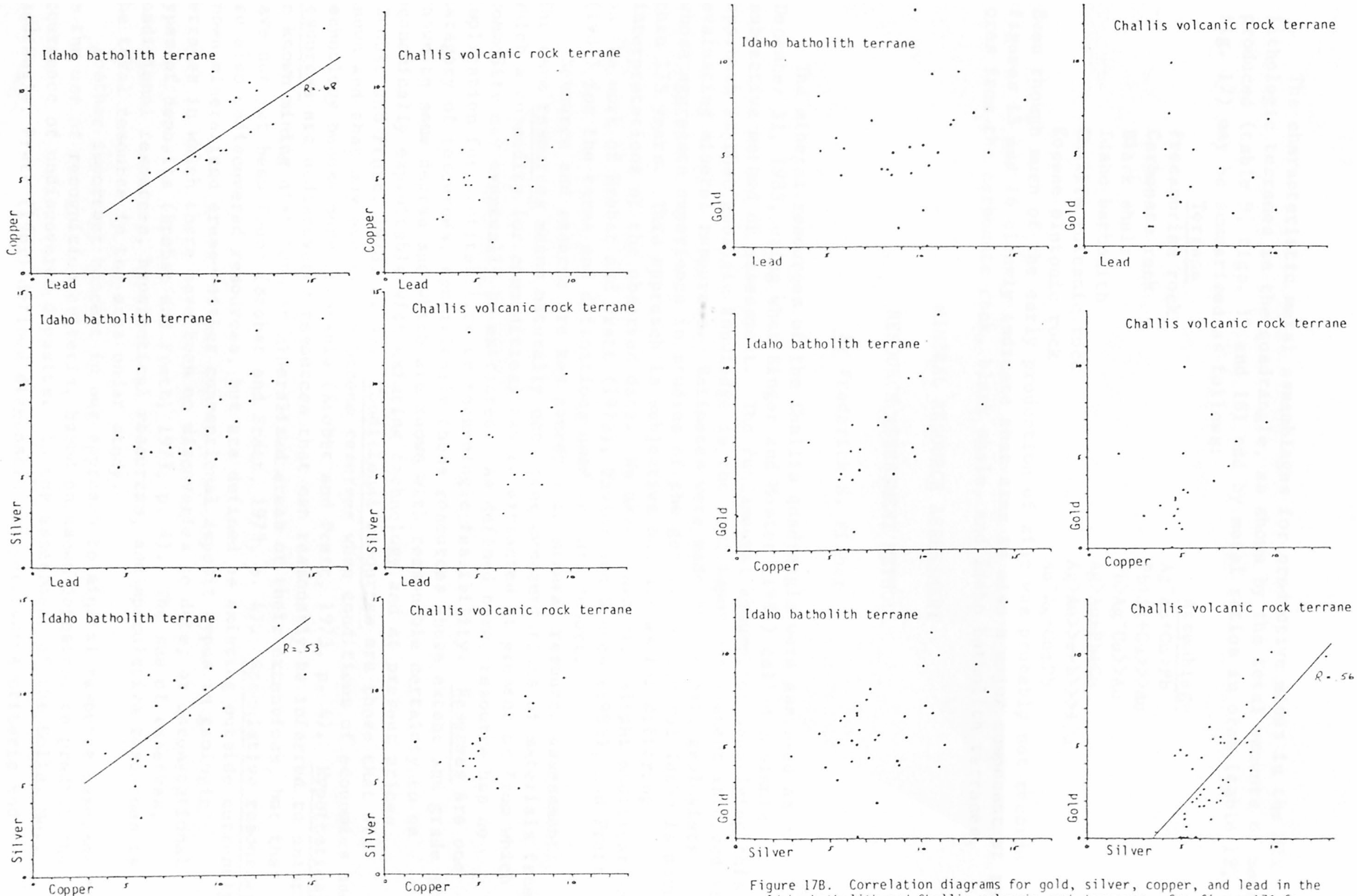


Figure 17B. Correlation diagrams for gold, silver, copper, and lead in the Idaho batholith and Challis volcanic rock terranes. See figure 17A for explanation.

The characteristic metal assemblages for productive mines in the six lithologic terranes in the quadrangle, as shown by the total amounts of metals produced (table 9, figs. 15 and 16) and by metal ratios in ores (table 12, fig. 17) may be summarized as follows:

Terrane	Assemblage
Precambrian rock	Ag~Au+Cu>Pb
Carbonate rock	Pb+Ag+Cu>>>Au
Black shale	Pb>Ag~Cu>>Au
Idaho batholith	Ag>Au±Pb±Cu
Challis volcanic rock	Ag>Au>>±Pb>>>±Cu
Eocene plutonic rock	Au~Ag+Co±Pb

Even though much of the early production of zinc was probably not recorded, figures 15 and 16 clearly indicate that zinc is also a major component of the ores from the carbonate rock, black shale, and Idaho batholith terranes.

MINERAL RESOURCE ASSESSMENT

RESOURCE ASSESSMENT METHOD

By Frederick S. Fisher

The mineral resources of the Challis quadrangle were assessed as of December 31, 1985, using what Singer and Mosier (1981) called a simple subjective method of assessment. The fundamental assumption underlying this approach is that geologic knowledge is the most important element involved in evaluating mineral resources. Estimates were made by economic geologists whose aggregate experience in studies of the geology of central Idaho is more than 175 years. This approach is subjective and allows for differing interpretations of the observed data. We have drawn with slight modifications on the work of Brobst and Pratt (1973), Taylor and Steven (1983), and Pratt (1981) for the terms and definitions used in this report.

Resource and reserve are key concepts in mineral resource assessment. The term *resources* means naturally occurring concentrations of materials from which a commodity (or commodities) can be extracted at present or from which a commodity may eventually be extracted. As defined here, resource has no implication for profitability or technologic feasibility. *Reserves* are one category of resources, specifically those resources whose extent and grade are known to some degree and which are known with reasonable certainty to be economically exploitable with existing technology and at present prices (Brobst and Pratt, 1973, p. 4). *Conditional resources* are those that are known and that may eventually become reserves when conditions of economics and technology become more favorable (Brobst and Pratt, 1973, p. 4). *Hypothetical resources* are undiscovered resources that can reasonably be inferred to exist in known mining districts or mineralized areas or their extensions, but that have not yet been found (Brobst and Pratt, 1973, p. 4). *Speculative resources* are also undiscovered resources, but are defined as existing outside currently known mineralized areas--either conventional deposit types in geologic terranes in which there have been no discoveries to date, or unconventional types of deposits (Brobst and Pratt, 1973, p. 4). The sum of reserves, conditional resources, hypothetical resources, and speculative resources is the total resource in the area under study.

Another important concept in our approach to mineral resource assessment is the use of recognition criteria, based on known deposits, to predict the occurrence of undiscovered deposits. In the assessment of the Rolla, Mo., quadrangle, Pratt (1981) defined diagnostic and permissive criteria and described their use in the assessment process. Diagnostic criteria are geologic parameters

> that are present in all, or nearly all, known deposits, and in most cases are considered to be required for the presence of a mineral deposit; conversely, the known absence of such criteria may either severely limit or definitively rule out the possibility of the presence of a deposit. Note, however, that the known absence of a geologic feature requires definite negative information . . . (p. 5)

Permissive criteria are

> those that are present in enough known deposits that they may be considered to favor the presence of a deposit, although they are not required. (p. 5)

The mineral resource assessment for the Challis quadrangle also employs terminology that describes the likelihood of occurrence of various deposit types in specific tracts. We have followed the usage of Taylor and Steven (1983) rather closely in this area and repeat their definitions here for the convenience of the reader. High mineral resource potential exists

> where geologic, geochemical, and geophysical characteristics favorable for resource accumulation are known to be present, or where enough of these characteristics are present to give strong support to genetic models favorable for resource accumulation and where evidence shows that mineral concentration--mineralization in the broad sense--has taken place. (p. 1269)

Moderate mineral resource potential exists

> where geologic, geochemical, and geophysical characteristics favorable for resource accumulation are known or can reasonably be inferred to be present but where evidence for mineralization is less clear or has not yet been found. (p. 1269)

Low mineral resource potential exists

> in areas where geologic, geochemical, and geophysical characteristics are unfavorable, where evidence indicates that mineral concentrations are unlikely, or where requirements for genetic models cannot be supported. (p. 1269)

Unknown mineral resource potential exists

> where the level of knowledge, at an appropriate scale, is so inadequate that to classify as high, moderate, or low would be misleading. (p. 1269)

Our method required eight sequential steps for each type of mineral deposit assessed. These steps are:

(1) identify terranes and describe their geology
(2) identify types of ore deposits known or suspected to occur in each terrane
(3) describe each ore deposit type
(4) list the recognition criteria for each deposit type
(5) divide the criteria into diagnostic and permissive, following the definitions above
(6) delineate areas on the map where diagnostic criteria are present
(7) score areas on the basis of the presence or absence of diagnostic and permissive criteria
(8) rank the areas based on their scores and on subjective weighting of geologic knowledge and experience.

Identification and description of the geologic terranes in the quadrangle (pl. 2) were based on the detailed mapping and field studies conducted over a six-year period (1978-1984). These studies are summarized on the geologic map

(Fisher and others, in press). Preliminary findings of the studies are presented in Fisher and others (1983) and in McIntyre (1985). The mineralization history of each of the terranes is different and in most cases involved several episodes of mineralization, the character of which was greatly influenced by the geology of the individual terrane.

The types of ore bodies in each terrane were determined by field studies. All of the mineral deposits in the Challis quadrangle known as of 1984 are briefly described and are shown on maps at scales of 1:250,000 and 1:125,000 published by the Idaho Geological Survey (Mitchell and others, 1981). All of the major ore deposits and most of the mineralized and altered areas were visited by at least one of the authors of this report. These field observations along with published and unpublished data were used to describe the ore deposit types. The descriptions include the following types of information wherever it was available:

(1) types and amounts of ore produced
(2) ages of ores and host rocks
(3) examples of deposit types in the Challis quadrangle
(4) characteristics of the ore body including the size, dimensions, character of contacts, shape, tonnage and grades of ores, mineralogy of ores and gangue, alteration of ore body and host rocks, major commodities and byproducts, and weathering of the ores and host rocks
(5) lithology of host rocks
(6) controlling structures
(7) geochemical and mineralogical indicators
(8) geophysical indicators
(9) isotopic data if pertinent

Limitations of time and personnel precluded the detailed examination of all mineral deposits; therefore because of strategic importance, critical supply, or industrial interest, more attention was focused on deposits containing gold, silver, tungsten, molybdenum, cobalt, uranium, fluorspar, vanadium, and tin.

From the deposit descriptions, recognition criteria were identified for each deposit type. These criteria are specific to the ore deposits in the Challis quadrangle. Mineral deposits of similar type outside of the Challis quadrangle may or may not have the same recognition criteria. The recognition criteria were then classified as being either diagnostic or permissive according to the definitions given above.

For each ore deposit type, maps were prepared at a scale of 1:250,000 showing distribution of all mappable criteria. Comparison of these maps with geologic maps of the area allowed visual integration of the recognition criteria with pertinent elements of each geologic terrane. Areas where diagnostic and permissive criteria were concentrated could then be readily identified.

Areas of diagnostic and permissive criteria shown on the maps were then scored as follows: widespread presence of a criterion was assigned a value of 1, known absence of a criterion was given a value of -1, and a lack of sufficient information to determine the presence or absence of the criterion was tallied as zero. The presence of the criterion in only part of the area was given a value of 1/2. The scores for each area were then summed, so that the sums thus represent relative favorability. The sums for the diagnostic and permissive criteria are considered separately because, by our definitions, the presence of permissive criteria enhances the favorability only if diagnostic criteria are also present in the area. If permissive criteria are lacking, the favorability is not lessened if diagnostic criteria are present.

Using the scores and any other available geological knowledge a resource potential of high, moderate, low, or unknown was assigned to each area. Maps showing the resource potential were then prepared for each ore deposit type. In many cases estimates of grade, tonnage, or value were not made for ore deposit types, areas, or individual commodities because of the lack of adequate data from drilling, mining, or sampling.

PRECIOUS-METAL VEINS

By Frederick S. Fisher, Thor H. Kiilsgaard,
Kathleen M. Johnson, and Earl H. Bennett, Idaho Geological Survey

Veins mined chiefly for gold and silver, but which also contain copper, lead, and zinc, occur at many locations in the Challis quadrangle. Gold has been the principal metal in terms of values produced, but in most veins silver has been the principal metal in terms of weight. Copper, lead, and zinc occur in variable amounts, ranging from minute quantities that are not recoverable to amounts substantial enough to be concentrated and marketed.

Typical precious-metal veins are in the Grimes Pass, Summit Flat, Stanley, Yankee Fork, and Gravel Range mining districts (pl. 1). Productive mines and some but by no means all of the prospects are shown on plate 3. Mines that have yielded a minimum of 100 oz of gold or 1,000 oz of silver are listed in table 13. Statistics on individual mine production prior to 1900 are incomplete or not available, and existing pre-1900 production figures are believed to be conservative.

The deposits are epithermal in type, as indicated by their mineralogy, ore and gangue mineral textures, and ore body habits. The position of ore in the veins appears to have been controlled in part by the pre-mineral land surface. The ore bodies are shallow; the richer portions are near the surface and the values diminish with depth. Most of the veins are in or associated with hydrothermally altered igneous rocks, many of Eocene age. Most of the veins are within the trans-Challis fault system (Kiilsgaard and Lewis, 1985). Many of the veins in the southwest part of the quadrangle strike northeast, parallel to the structures that define the trans-Challis fault system. In the central and northeast parts of the quadrangle, some veins strike northeast, but many follow secondary faults of diverse trends.

The Tertiary age of mineralization is demonstrated by field relations and radiometric dating. Many veins are in Cretaceous granitic rocks of the Idaho batholith. Others are in Tertiary plutonic or volcanic rocks dated at 48 to 45 m.y. (Kiilsgaard and Bennett, this volume, p. 54). Veins in both Cretaceous and Tertiary host rocks are commonly associated with Tertiary dikes, mostly of rhyolitic composition. The veins either extend along the dikes or cut across them. Potassium-argon dating of sericite from the General Custer vein yielded ages ranging from 48.4 to 44 m.y. (R.F. Marvin, written commun., 1983). A rhyolite dike at the Little Falls molybdenum deposit on the South Fork of the Payette River yielded fission-track ages on zircon of 29.3±1.7 m.y. (P. Andriessen, written commun., 1982); and veinlets of molybdenite cut the dike. The rhyolite dike is part of a swarm of rhyolite dikes, some of which are cut by precious-metal veins in Boise Basin. Also in Boise Basin, some precious metal veins are cut by rhyolite dikes (Ballard, 1924) which suggests that dike intrusion and mineralization were more or less contemporaneous. The radiometric ages indicate that mineralization extended over a period of at least 15 m.y. and probably was episodic. Field

Table 13. Metals produced from precious-metal veins, through 1984, Challis quadrangle

[Includes properties that have produced more than 100 ounces of gold or 1,000 ounces of silver. Sources of data: Anderson, 1949; Anderson and Rasor, 1934; Choate, 1962; Ross, 1934b; Tschanz and others, 1974; Umpleby, 1913a and b; and unpublished records of U.S. Bureau of Mines, Spokane, Wash.; --, no data]

	Gold	Silver	[1]Copper	[1]Lead	[1]Zinc	Pre-1900 production
	oz		lbs			dollars
			Banner district			
Banner	45	47,899	465	317	--	3,000,000
			Boise Basin (Grimes Pass and Summit Flat districts)			
Black Jack	156	92	--	--	--	--
Comeback	11,840	343,374	17,020	152,886	1,583	--
Coon Dog	734	7,892	26,737	104,762	11,735	--
Enterprise	255	2,427	11,131	51,419	--	--
Gold Belt	206	107	--	--	--	--
Golden Age	9,936	20,842	9,402	38,441	--	--
Golden Chariot	1,267	614	--	--	--	--
Golden Cycle	1,664	1,016	--	--	--	--
Grand View	172	238	--	100	--	--
Independence	158	632	--	4,536	--	--
J & S	284	128	--	--	--	--
KC Group	348	719	47	227	--	--
Mammoth	576	263	--	--	--	--
Missouri	116	9,140	462	20,527	1,944	--
Mohawk	78	1,124	715	30,202	--	--
Mountain Queen	27	1,294	680	1,559	--	--
San Cristobal	103	43	--	--	--	--
Silver Gem	65	5,268	4,237	3,497	--	--
Sloper (Jessie)	730	319	--	--	--	--
Smuggler	1,918	14,546	5,484	386,410	--	--
			Deadwood district			
Mary Blue and Union	3,104	1,333	--	--	--	--
			Gravel Range district			
Rabbit Foot	116	136	--	--	--	--
Singheiser	317	8,415	2,543	--	--	--
			Lowman vicinity			
Idaho Birthday	821	657	472	1,625	--	--
Specimen	295	88	--	--	--	--

Table 13. Metals produced from precious-metal veins, through 1984, Challis quadrangle--Continued

	Gold	Silver	Copper[1]	Lead[1]	Zinc[1]	Pre-1900 production
	oz		lbs			dollars
Parker Mountain District						
Ed Williams (White Rock)	216	776	--	--	--	--
Parker Mine (Pitch Hit)	603	3,744	--	--	--	--
Stanley district						
Gold Chance	290	--	--	--	--	6,000
Valley Creek and Buckskin	5,262	33,866	1,818	70,200	--	--
Yankee Fork district						
Arcade	8	1,194	--	--	--	--
Badger Group	102	5,765	--	--	--	--
Charles Dickens	78	423	--	--	--	600,000 (1888-1902)
Estes Mountain	39	2,241	100	100	--	--
Fairplay	8	624	--	--	--	20,000-25,000
General Custer	177	1,143	5	320	--	8,000,000 (to 1905)
Golden Sunbeam (including Bismark)	18,160	23,778	--	--	--	--
Jordan	173	4,492	--	--	--	--
Julietta	87	105	--	--	--	Few thousand dollars
Letha	1	61	--	--	--	60,000
Lucky Boy	17,502	302,001	166	93	--	1,750,000 (to 1904)
McFadden	73	8,983	974	6,900	--	200,000
Montana Group	1,963	18,706	--	--	--	337,000
Morrison	--	--	--	--	--	100,000
Passover	--	--	--	--	--	20,000-25,000
Peak	1,224	4,450	710	64	--	--
Snowdrift	175	1,473	159	71	--	--
Whynot	820	34,896	12,492	15,387	--	--
Yankee Fork	83	13,101	1,670	1,144	--	--
Yellowjacket district						
Bryan	377	137	3,551	1,541	--	--
Silver Moon (Liberty)	4	1,244	169	4,106	4,015	--
Tin Cup	136	111	3,977	108	--	--
Yellowjacket	2,972	3,440	4,402	7,650	100	121,762

[1]Copper, lead, and zinc were not always recovered in early days. Ore and concentrates that contained zinc were penalized at the smelter.

observations indicate that hydrothermal alteration near the veins both preceded and was concurrent with vein mineralization.

Descriptive Model

Ore Body

Size: Ore shoots along the veins tend to be small. They range from lenticular pods a few feet in strike and dip length and a few inches thick to bodies more than 100 ft in strike length, more than 100 ft in dip length, and 3 or more feet thick.

Shape: Lenses, pods, planar veins, and aggregates of veinlets that range from convergent to more or less parallel. Shapes of ore bodies were determined largely by the permeability and geometry of the host fracture.

The veins occur in fractures formed from fault adjustment and are chiefly simple fracture fillings. They commonly occur along shear zones, with one wall defined by the shear plane and the other in sharp contact with the host rock. Some veins are filled with breccia composed of ore minerals, fragments of host rock, and early stage quartz in a matrix of quartz, ore minerals, and other sulfide minerals. Other types of veins include aggregates of small, more or less parallel, fracture fillings and single veins with well-defined walls.

Tonnage and grade: Deposits range from a few tens to a few thousands of tons. Grade of ore is irregular, both within a single vein and between deposits, and ranges from a trace to 23 oz of gold per ton and from a trace to 2,500 oz of silver per ton. Assay information on ore mined from 12 deposits in Boise Basin indicates an average grade of about 0.50 oz gold per ton and about 10 oz silver per ton. Minor amounts of copper, lead, and zinc occur in some deposits (table 8); the ore ranges in grade from trace to 5 percent copper, trace to 3 percent lead, and trace to 7 percent zinc. Grades of ore produced from the Yankee Fork district range from 0.4 to 23 oz gold per ton and from trace to 2,500 oz silver per ton. Most deposits in the Yankee Fork district produced only small amounts of copper and lead; exceptions are the McFadden and Whynot deposits (table 8). In the Yellowjacket district, grades of ore ranged from 0.009 to 0.81 oz gold per ton; from 0.397 to 92.0 oz silver per ton; from 0.019 to 8.0 percent copper; and from 0.018 to 17.2 percent lead (calculated from Anderson, 1953).

Mineralogy

Ore minerals: auriferous pyrite, native gold, electrum, tetrahedrite, miargyrite, pyrargyrite, proustite, argentite, stephanite, owyheeite, aguilarite, native silver, various bismuth sulfides, galena, chalcopyrite, enargite, and sphalerite (Anderson, 1947 and 1949; Anderson and Rasor, 1934; Ballard, 1924; Ross, 1937b).

Electrum is the most significant ore mineral at most deposits. Auriferous pyrite is present in some deposits and tetrahedrite is the most common silver sulfide. In most deposits, sulfide minerals are sparse and fine grained.

Gangue minerals: quartz, calcite, adularia, siderite, barite, pyrite, pyrrhotite, and arsenopyrite.

Quartz is the dominant gangue mineral and the guide to ore at most deposits. It ranges from cryptocrystalline to coarse, with finer grained quartz often along the vein walls and coarser quartz, sometimes comb structured, in central parts of the vein. Older quartz tends to be gray to milky in color, whereas younger quartz is clear and vitreous. Clear quartz often is darkened locally by included minute crystals of pyrite or other sulfides.

Commodities

Major commodities produced are gold and silver. Lead, copper, and zinc have been produced as byproducts.

Character of ore

Ore minerals tend to be discontinuous in the vein. They form clustered bunches or lenses, sometimes as crustification bands in quartz that are parallel to vein walls or concentric around vugs. Bands of ore minerals range from a knife edge to an inch or so in thickness. Ore minerals also may be in vugs, deposited on crystal faces, or disseminated in vein quartz, breccia fragments, or altered wall rock adjacent to veins. In some cases, altered barren rock can be distinguished from ore only by assay.

Weathering products

Weathered products in the veins depend on the rate of erosion and on mineral constituents of the veins. Depth of oxidation ranges from 0 to 100 ft in most structures. Veins with abundant pyrite weather to conspicuous dark-reddish-brown gossan; many of these were mined for their gold content. In such weathered rocks, gold is concentrated by residual enrichment. Also, some gold may have been remobilized during the process of oxidation and deposited as supergene gold. Oxidized silver minerals are difficult to identify in the weathered zone because of their small grain size and because they tend to be stained by iron oxides. Oxidized tetrahedrite commonly leaves a faint blue-green copper stain in the weathered material. Galena oxidizes to cerussite and anglesite and sphalerite oxidizes to smithsonite and calamine, but because the sulfide minerals generally are present in small amounts, the secondary minerals rarely are seen.

Lithology of host rock

Principally in Tertiary and Cretaceous igneous rocks. Also found in Precambrian metasedimentary rocks.

Alteration

Alteration of host rocks ranges from moderate to intense. In the Yankee Fork district, propylitized rocks are widespread away from the veins, whereas near the veins the wallrocks have been more intensely altered by silicification and argillization. Criss and others (1985) have described low $^{18}O/^{16}O$ ratios in the intensely altered rocks. Wallrocks adjacent to veins in Boise Basin are commonly bleached and altered. Sericite, formed from the feldspars and to a lesser extent the ferromagnesian minerals, is widespread. In more intensely altered areas the wallrocks are also silicified. Pyrite is widespread in the altered zones (Anderson, 1947).

Geochemical and mineral indicators

Sediments from streams that are eroding precious-metal vein deposits are enriched in gold, silver, copper, lead, zinc, and molybdenum (McDanal and others, 1984; McIntyre and Johnson, 1985). The association of gold with bismuth minerals in more productive parts of certain Boise Basin veins is described by Ballard (1924), Ross (1937b), and Anderson (1947). Gold-bearing veins at the Buckskin and Valley Creek mines in the Stanley district are enriched in arsenic and mercury (Tschanz and others, 1974).

Ore controls

1. Trans-Challis fault system
   Pre-mineral adjustment along faults of the system created fractures for mineral deposition.
2. Fracture permeability
   Open fractures are permeable to mineralizing solutions. Intersecting fractures, variation in strike and dip along the fractures, and shattered zones formed from many parallel to intersecting fractures contributed to the permeability of rocks undergoing mineralization. At intersections of fractures with gouge-filled pre-mineral faults, the gouge served as an impermeable barrier, diverting mineralizing solutions into the permeable fractures (Ballard, 1924).
3. Pre-mineral land surface
   The tendency for metal values in ore bodies to diminish at shallow depths and the epithermal character of the ore indicates a narrow vertical range of mineral deposition. The location of the mineralized zone appears to have been influenced by proximity to the pre-mineral surface. In most mines the veins are barren below a depth of 500-600 ft.
4. Eocene intrusive rocks
   The ore bodies commonly occur within, alongside, or near dikes and stocks of Eocene age. Mineralization in the veins appears to be genetically related to Eocene intrusive activity.
5. Competence of wall rock
   Fractured and shattered zones in dense brittle rock such as rhyolite were more open and permeable to mineralizing solutions than were gouge-filled shear zones in altered and incompetent granitic rock.

Geophysical indicators

Resistivity surveys might help define zones of intense alteration, and electromagnetic surveys might delimit veins in which enough sulfide minerals are present to serve as an electrical conductor.

Resource Assessment

From the descriptive model above, we define 10 recognition criteria, of which four are diagnostic and six permissive.

Diagnostic criteria

1. Evidence of precious metal mineralization. This may be either geochemical anomalies, mines or prospects, or placer deposits.
2. Presence of planar high-angle fault or fracture. Deposits of this type are found only where there has been high-angle faulting.
3. Presence of Tertiary hypabyssal intrusive rocks, including dikes, stocks, and plugs. These rocks are generally felsic in composition.
4. Presence of open-space filling materials in faults and fractures.

Permissive criteria

1. Proximity to trans-Challis fault system. All but one of the major producing precious-metal vein deposits (pl. 3) lie within the trans-Challis fault system. For this reason, areas within the trans-Challis fault system are considered most favorable. Areas less than 5 mi outside the trans-Challis fault system are considered somewhat less favorable and those farther away are considered unfavorable.
2. Evidence of widespread propylitization, including presence of chlorite, calcite, sericite, epidote, and pyrite.

3. Localized areas of intensely altered rocks containing secondary silica or clay minerals.
4. Proximity to a mine that has historic production of more than 100 oz of gold or 1,000 oz of silver.
5. Presence of prospects (including small mines).
6. High levels of copper, lead, and zinc in stream-sediment samples.

Using the diagnostic recognition criteria the quadrangle was divided into 51 areas (pl. 3). The area boundaries were first tentatively established around localities containing evidence of precious-metal mineralization. They were then adjusted by considering the presence, absence, and density of mapped Tertiary hypabyssal intrusions and high-angle faults. Each of the areas was scored according to its diagnostic and permissive criteria (see Fisher, this volume, p. 114, for an explanation of the scoring process). The scores are tabulated in table 14.

Within any area, potential for this type of deposit exists only along planar faults or fractures. Because our mapping was compiled at 1:250,000 scale, not all known faults are shown. It is also probable that not all faults have been recognized.

On the basis of the scores shown in table 9, areas 9, 10, 11, 31, 34, 37, 46, 47, and 49 are ranked as having a high potential for the presence of additional precious-metal vein deposits. This is to say that in each of these areas we believe it is highly probable that at least one undiscovered deposit, similar in character and size to the model given above, is present.

Areas 5, 15, 25, 42, and 45 are ranked as having a moderate resource potential. This is to say that precious-metal vein deposits may exist in these areas, but in our judgment the probability of their existence is much lower than in the areas ranked as having high potential.

Areas 1-4, 6-8, 12-14, 16-24, 26-30, 32, 33, 35, 36, 38-41, 43, 44, 48, and 50 were ranked as having a low potential. We believe there is little chance of productive precious-metal vein deposits in these areas. It should be noted that areas 1-4, 7, 12, 13, 17, 21, 29, 32, 33, 35, 36, 40, 41, 43, 48, and 50 were delineated solely on the basis of either geochemical anomalies or precious-metal placer deposits. Because the bedrock source of the metals in these areas is not known, the entire drainage basin of each area may be considered as having a low potential. We drew area boundaries only around the immediate locality of the anomalies or placers to indicate that precious metal-bearing rocks do occur somewhere in the drainage. We did not include the entire drainage because we believe it would give an erroneous impression of the size of the area under consideration and of the importance of a limited geochemical data set.

The remainder of the quadrangle, that is the areas not considered above, has a low potential for additional precious-metal vein deposits due to absence of diagnostic criteria. More detailed work in these areas could bring to light evidence of the sort we have used to delineate potential, but no such information is known to us at this time.

Additional potential for gold and silver resources exists in disseminated deposits in the broad zones of altered rock that are found adjacent to some major precious-metal veins. In the Yankee Fork district, the altered andesites around the Lucky Boy and General Custer veins were drilled in 1982-84 (Thorney Rogers, oral commun., 1983). These altered zones are as large as hundreds of feet in width and thousands of feet in length. Rocks within the zones have been extensively fractured, are commonly bleached, and in places are stained with iron oxides. Propylitically altered rocks are widespread; near the veins silicified and sericitized rocks are well

Table 14. Recognition criteria for precious-metal veins (see pl. 3)

Map area	Diagnostic criteria: Evidence of precious metals	Planar high-angle faulting	Tertiary hypabyssal intrusives	Open space filling	Total	Permissive criteria: Proximity to trans-Challis fault system	Widespread, previously altered rocks	Locally altered rocks	Proximity to major mines	Proximity to prospects	Cu/Pb/Zn anomalies	Total	Resource potential
1	1/2	1/2	0	0	1	-1	0	0	-1	1/2	-1	-2 1/2	Low
2	1	1/2	0	0	1 1/2	-1	0	1	-1	1/2	-1	-1 1/2	Low
3	1/2	0	0	0	1/2	-1	0	0	-1	1/2	-1	-2 1/2	Low
4	1/2	1/2	0	0	1	-1	0	0	-1	-1	-1	-4	Low
5	1	1	1/2	0	2 1/2	-1	1	1	-1	1	1/2	1 1/2	Moderate
6	1	1/2	0	0	1 1/2	-1	0	0	-1	1/2	1/2	-1	Low
7	1	0	1/2	0	1 1/2	-1	0	0	-1	1	-1	-2	Low
8	1	0	0	0	1	-1	0	0	-1	1	-1	-2	Low
9	1	1	1	1	4	1	1	1	1	1	1	6	High
10	1	1	1	0	3	1	1	1/2	-1	-1	-1	- 1/2	High
11	1	1	1/2	1	3 1/2	1	1	1	1	1/2	1/2	5	High
12	1/2	1/2	0	1/2	1 1/2	-1	1	0	-1	1	1	1	Low
13	1/2	0	0	0	1/2	-1	0	0	-1	0	1	-1	Low
14	1/2	1	1	0	2 1/2	1/2	0	0	-1	0	-1	-1 1/2	Low
15	1/2	1/2	1	1/2	2 1/2	1	1	1	-1	-1	-1	0	Moderate
16	1/2	0	1	0	1 1/2	1/2	0	0	-1	1/2	1/2	1/2	Low
17	1	0	1/2	0	1 1/2	-1	0	0	-1	1	-1	-2	Low
18	1	1/2	1	0	2 1/2	-1	0	0	-1	1	-1	-2	Low
19	1	1/2	1	0	2 1/2	-1	1/2	0	-1	1	1/2	0	Low
20	1	1/2	0	0	1 1/2	-1	1	1/2	-1	1	1/2	1	Low
21	1/2	1/2	1	0	2	-1	0	0	-1	-1	1/2	-2 1/2	Low
22	1	0	1	0	2	-1	1	1/2	-1	-1	1/2	-1	Low
23	1	0	1	0	2	-1	1	1/2	-1	1	1/2	1	Low
24	1	0	1	0	2	-1	0	0	-1	1	-1	-2	Low
25	1	0	1	0	2	1/2	1	1	-1	1	1	3 1/2	Moderate
26	1	0	1	0	2	1/2	0	0	-1	1	-1	- 1/2	Low
27	1	0	1	0	2	1/2	0	0	-1	1	-1	- 1/2	Low
28	1/2	1/2	1	0	2	1	1/2	0	-1	1/2	-1	0	Low
29	1	1	0	0	2	-1	0	0	-1	-1	1/2	-2 1/2	Low
30	1	1/2	0	0	1 1/2	-1	1	1/2	-1	1	1	1 1/2	Low
31	1	1	1	1	4	1	1	1	1	1	1/2	5 1/2	High
32	1/2	1	1	0	2 1/2	1	0	0	-1	-1	-1	-2	Low
33	1	1	0	0	2	1	1	0	-1	-1	1/2	1/2	Low
34	1	1	1/2	1	3 1/2	-1	1/2	1/2	1	1/2	1/2	2	High
35	1	1/2	0	0	1 1/2	-1	0	0	-1	-1	-1	-4	Low

Table 14. Recognition criteria for precious-metal veins--Continued

Map area	Diagnostic criteria: Evidence of precious metals	Planar high-angle faulting	Tertiary hypabyssal intrusives	Open space filling	Total	Permissive criteria: Proximity to trans-Challis fault system	Widespread, previously altered rocks	Locally altered rocks	Proximity to major mines	Proximity to prospects	Cu/Pb/Zn anomalies	Total	Resource potential
36	1	0	1/2	0	1 1/2	-1	0	0	-1	-1	1/2	-2 1/2	Low
37	1	1/2	1	1	3 1/2	1	1	1	1	1	-1	4	High
38	1	0	0	0	1	1	1/2	0	-1	1	-1	1/2	Low
39	1/2	1/2	1	0	2	1/2	0	0	-1	1/2	1	1	Low
40	1/2	1	1/2	0	2	-1	0	0	-1	-1	-1	-4	Low
41	1/2	1/2	0	0	1	-1	0	0	-1	-1	-1	-4	Low
42	1/2	1	1	1/2	3	-1	1/2	1/2	-1	1/2	-1	-1 1/2	Moderate
43	1/2	0	0	0	1/2	-1	0	0	-1	-1	1	-2	Low
44	1	0	1/2	0	1 1/2	-1	0	0	-1	-1	1	-2	Low
45	1	1/2	1	0	2 1/2	1/2	1/2	1/2	-1	-1	1	1/2	Moderate
46	1/2	1	1	1/2	3	1	1	1/2	1	1/2	1/2	4 1/2	High
47	1	1/2	1	1/2	3	1	1	1/2	1	1/2	1	5	High
48	1/2	1/2	1	0	2	1	0	0	-1	-1	1/2	- 1/2	Low
49	1	1	1	1	4	1	1	1	1	1	1	6	High
50	1/2	1/2	0	0	1	1/2	0	0	0	1/2	-1	0	Low
51	(see text)												Low

developed. Fine-grained pyrite is ubiquitous, but most of it has been oxidized. Extensively altered rocks also are known in the Boise Basin, such as adjacent to the Comeback, Independence, and Coon Dog mines.

We do not have enough information about these disseminated deposits to write a complete description and resource appraisal. However, we believe that the diagnostic criteria would be similar to those used to describe the precious-metal veins. Large disseminated deposits are likely to occur in association with the largest vein deposits, where faulting and fracturing were extensive. These ore bodies may be as large as millions of tons, with ore grades of 0.0x oz of gold per ton. Deposits of this type may be a much greater precious-metal resource than the associated higher grade veins.

MIXED BASE- AND PRECIOUS-METAL VEINS

By Thor H. Kiilsgaard and Earl H. Bennett

INTRODUCTION

Galena, sphalerite, and chalcopyrite are principal base-metal minerals in a large number of veins in the Challis quadrangle. Most of these veins also contain notable quantities of silver minerals and gold. Indeed, the veins were explored primarily for their contained gold and silver, which have been of more commercial value than the contained base-metal minerals, but the latter are more consistent throughout the veins and constitute the bulk of the ore bodies. Veins in this group are similar in many respects to previously described precious-metal veins; however, they appear to differ genetically. Mixed base- and precious-metal veins may be Cretaceous in age and may be genetically related to the Idaho batholith, whereas precious-metal veins are believed to be Tertiary in age. In addition, most precious-metal veins are spatially related to the trans-Challis fault system, whereas many mixed base- and precious-metal veins show no relation to that fault system. In the remainder of this chapter, we will refer to mixed base- and precious-metal veins as mixed veins, for simplicity.

Mixed veins are chiefly in the Deadwood, Seafoam, Sheep Mountain, and Loon Creek mining districts (Ross, 1936; pl. 1, this volume). Many of the deposits are north of the Seafoam, Sheep Mountain, and Loon Creek districts but south of the Thunder Mountain cauldron complex (fig. 1). Several deposits in the Pioneerville district (pl. 1), classified as precious-metal veins, have also produced significant amounts of base metals. Of these, the Coon Dog, Golden Age, and Comeback mines are most significant. Precious- and base-metal production from these mines, and others in the Pioneerville district, is listed in table 13. Copper and lead have been mined from the Twin Peaks mine, in the northeast corner of the quadrangle. The ore minerals, chiefly chalcopyrite and galena, came primarily from low-angle bedding veins at two different stratigraphic horizons of Precambrian metasedimentary rocks. The Twin Peaks deposit is discussed under the section on stratabound cobalt-copper deposits (Johnson and Bennett, this volume, p. 209).

The largest and most productive mixed vein is at the Deadwood mine, which, as considered here, represents a consolidation of three contiguous mines, the Deadwood, Hall-Interstate, and Pilgrim. Other large mixed veins occur at the Lost Packer, Greyhound, Seafoam, and Mountain King mines. Veins at all four of the properties have been explored over hundreds of feet of strike length, with some vein thicknesses up to 20 ft. Most of the mixed veins in the quadrangle, however, are small, and have produced only minor amounts of ore. Recorded production from 1900 to 1984 is shown in table 15,

Table 15. Production from mixed veins, 1904 to 1984

[Unpublished U.S. Bureau of Mines data, Spokane, Wash.]

	Gold	Silver	Copper	Lead	Zinc
	oz		lb		
Cougar Group	183	483	--	341	--
Deadwood[1]	2,663	644,173	444,723	4,979,459	10,176,833
Greyhound	42	13,148	682	10,865	4,551
Lost Packer	19,790	48,451	1,797,786	--	--
Lucky Lad (Lucky Boy)	1,309	24,165	2,897	332,716	--
Mountain King	159	60,534	12,744	728,222	758,260
Seafoam and Silver King	210	1,560	435	11,243	16,000
Sunrise Group	--	417	--	8,038	--

[1]Includes Hall-Interstate, Lost Pilgrim, and Deadwood mines.

and locations of most of the known deposits are shown on plate 4 and in Mitchell and others (1981).

Origin of the mixed veins is not clearly understood, but field evidence suggests they may be related genetically to the Idaho batholith. Most of the deposits are in granitic rocks of the batholith, and many of them are near or partially within roof pendants of metamorphosed sedimentary rocks. The roof pendants and the nearby veins are considered to be in the upper zone of the batholith. Some of the veins are in leucocratic granite, which is the youngest of the Cretaceous plutonic rocks. At none of the deposits that were examined is there clear evidence of genetic relation to Eocene plutonic or hypabyssal rocks even though such rocks occur near many of the deposits. Mafic dikes, believed to be of Tertiary age, intrude the Deadwood vein, but there are no reports of mineralized dikes in the Deadwood mine area. Ross (1930) described an andesitic dike that cuts and offsets the Greyhound vein, and he noted that porphyritic dikes near the Seafoam mine are younger than the mineralized vein. His interpretation differs from that of Treves and Melear (1953), who believe the dikes are cut by the Seafoam vein. Dikes of probable Eocene age cut the Lost Packer vein, which is partly hosted in leucocratic granite. Sericite from the vein, dated by the $^{40}Ar/^{39}Ar$ age-spectrum technique, gave an age of about 77 m.y. (Snee and Lund, 1985). The sericite age is compatible with that of the leucocratic granite host rock, muscovite from which has been dated by the potassium-argon method at 75.0 ± 1.7 m.y. (R.F. Marvin, written commun., 1985).

Descriptive Model

Ore Body

Size: A large ore shoot at the Deadwood mine was 160 ft in strike length, 125 ft in dip length, and had a maximum thickness of 20 ft (J.W. Gwinn, written commun., 1940). The largest of three ore shoots at the Lost Packer mine had an average strike length of 300 ft, ranged from a few inches to 5 ft in thickness, and was developed downdip for about 700 ft (Umpleby, 1913b). Eleven hundred feet of drift on the Lower Rufus level of the Greyhound mine (to November, 1986) exposed three ore shoots in the Greyhound vein, each about 75 ft in strike length and about 8 ft in thickness (S. Hornbaker, verbal commun., 1987). On the 7,200 ft adit level, the Seafoam vein is 4 to 5 ft thick (unpublished DMEA report, 1956), but the size of any ore shoots is unknown to the authors. Most mixed veins of the quadrangle are small and ore pods and lenses in them commonly are a few inches to a foot or so thick and tens of feet long.

Shape: Lenticular ore shoots with considerable range in thickness, and sharp wallrock contacts.

Tonnage and grade: Tonnage and grade range widely in the veins. At the Deadwood mine, a total of 125,293 tons of ore, mined from 1929 to 1950, averaged 0.0214 oz gold per ton, 5.115 oz silver per ton, 0.18 percent copper, 1.98 percent lead, and 4.06 percent zinc. Millhead samples of higher grade ore from the largest stope in the Deadwood mine, over a period of one month, assayed 0.067 oz gold per ton, 15.12 oz silver per ton, 0.39 percent copper, 8.15 percent lead, and 9.30 percent zinc (J.W. Gwinn, written commun., 1940). High-grade chalcopyrite ore from the Lost Packer mine assayed from 2 to 20 oz gold per ton and 15 percent copper (Jennings, 1906), but an average grade was about 0.5 oz gold per ton, 2 to 3 oz silver per ton, and 3.5 to 4.5 percent copper (Umpleby, 1913b). A total of 9,873 tons of ore was mined from the Lost Packer vein, from

1902 to 1984, the recovered metal content of which is shown in table 15. Samples from three ore shoots on the Lower Rufus level of the Greyhound vein ranged from 0.03 to 0.06 oz gold per ton, 5 to 15 oz silver per ton, 3 to 4 percent lead, and 4 to 5 percent zinc (S. Hornbaker, verbal commun., 1987). Samples from smaller mixed veins in the quadrangle range from trace to 1 oz gold per ton, trace to 48 oz silver per ton, 0.01 to 4 percent copper, 0.10 to 38 percent lead, and 0.01 to 5 percent zinc.

Mineralogy

The ore minerals are chiefly galena, sphalerite, and chalcopyrite. Auriferous chalcopyrite is the principal ore mineral at the Lost Packer mine. Tetrahedrite occurs at some deposits (Cater and others, 1973). At some deposits, silver content increases as the amount of galena increases. Gold may occur with pyrite at some deposits. The gangue minerals are quartz, siderite, calcite, pyrite, pyrrhotite, and arsenopyrite.

Major commodities

Zinc, lead, copper, silver, and gold.

Character of ore

Ore shoots at the Lost Packer mine are composed of massive auriferous chalcopyrite. The ore shoots have well-defined walls, and the richer ore is in the center of the shoot. Streaks and bands of ore minerals in siderite and quartz characterized low-grade parts of the Deadwood vein; the ore shoots consisted of bunchy aggregations of ore minerals, according to Oscar Hershey (written commun., 1929). R.P. Full (written commun., 1944) described vein quartz at the Deadwood deposit as having been brecciated and subsequently replaced by siderite. The earliest sulfide was marmatitic sphalerite, followed by galena and chalcopyrite. The ore minerals replaced the siderite; however, where siderite was not present, the ore minerals replaced massive quartz. Silver apparently was present in both the galena and the sphalerite. Ore shoots in the Greyhound vein consist of massive quartz, galena, and sphalerite. Silver values increase as the content of lead increases. Pyrite, galena, and sphalerite in quartz gangue form lenses along the Seafoam shear zone. Irregular lenses of quartz which include banded to massive occurrences of sulfide ore characterize many of the mixed veins.

Weathering products

Outcrops of mixed veins exhibit different degrees of weathering, depending on the terrain. Primary sulfide minerals at the Deadwood vein are exposed near the surface on the steep, glacially scoured slope above the mine. Jennings (1906) described a zone of oxidation extending 30 to 40 ft below the surface at the Lost Packer mine, but Ross (1934b) noted primary sulfides near the surface. Significant quantities of oxidized ore minerals have not been mined from the mixed veins.

Lithology of host rocks

Granitic rocks of the Idaho batholith host most of the veins. Some veins cut roof pendants of metamorphosed sedimentary rocks. No outcrop of roof pendant is known along surface exposures of the Deadwood vein; however, unpublished maps of the Deadwood mine (R.P. Full, written commun., 1944) show ore shoots in roof pendant gneiss.

Alteration

Hydrothermally altered rock rarely extends more than a few feet from the vein walls. Argillic and sericitic alteration of the feldspars in the wall rock is most common, although some wall rock is silicified locally. Extensive alteration has not been found away from the veins and shear zones, a condition that contrasts sharply with the widespread alteration that accompanies precious-metal veins in the trans-Challis fault system.

Geochemical and mineral indicators

Anomalous quantities of lead, zinc, copper, and silver are common in stream sediments that are downstream from exposures of eroding mixed veins. Oxidized lead-zinc-copper minerals occur in well-weathered surface exposures of the veins.

Controlling structures

Shear zones and fractures control location of the ore bodies.

Geophysical indicators

Concentrations of certain sulfide minerals may be detected by electromagnetic surveys.

Isotopic data

Samples from the K.G., Mountain King, Seafoam, and Silver Bell mines show low radiogenic ratios of $^{206}Pb/^{204}Pb$ (table 16) and higher radiogenic values of $^{208}Pb/^{204}Pb$, which suggest to B.R. Doe (written commun., 1984) that the lead could have originated in the Precambrian basement. By contrast, higher $^{206}Pb/^{204}Pb$ ratios of the Deadwood and Lost Packer samples suggest to Doe that the lead came from a mixture of Archean and younger crustal materials. If Doe (1974) is correct in suggesting that lower radiogenic lead values are associated with more attractive ore deposits, perhaps there is unrecognized potential at the K.G., Mountain King, and other properties with low radiogenic lead values.

Resource Assessment

From the foregoing descriptive model we define 10 recognition criteria of which four are diagnostic and six are permissive:

Diagnostic

1. Presence of base and precious metals.
2. Presence of high-angle planar fractures or faults.
3. Presence of granitic rocks of the Idaho batholith.
4. Presence or proximity of roof pendants of metamorphosed sedimentary rock.

Permissive

1. Presence or proximity of leucocratic granite.
2. Absence of evidence indicating genetic association to Tertiary hypabyssal or plutonic rocks.
3. Presence of wall rock alteration.
4. Presence of anomalous metals in stream sediments.
5. Proximity to productive mines.
6. Proximity to known mixed vein prospects.

Using studies of published and unpublished geologic and geochemical information and our knowledge of the region, we have subdivided parts of the quadrangle underlain by, or contiguous with, the Idaho batholith into 25 study areas. We have assessed each of these areas separately, using the above 10 recognition criteria. Scores of the evaluation are shown in table 17. From these semiquantitative scores, we interpret the resouce potential of the areas as follows:

Table 16. Lead isotope data, mixed base- and precious-metal veins

[Locations shown on plate 4. Maryse Delevaux, U.S. Geological Survey, analyst]

Sample No.	Material	Mine name	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
				Atomic ratios	
R151	Galena--	K.G.[1]---------	17.990	15.578	39.286
R154	--do----	Mountain King[2]	17.943	15.606	40.299
K52-1	--do----	--do----------	17.810	15.593	40.290
F154	--do----	Seafoam pros.-	17.747	15.604	39.765
R155	--do----	Silver Bell[3]--	17.596	15.574	39.785
KR880	--do----	Deadwood------	19.341	15.754	39.527
KR743	Feldspar	--do----------	19.488	15.716	39.320
LP-1	Rock----	Lost Packer---	19.768	15.742	40.078

[1]Location (44°33′32" N., 115°20′20" W.) not labeled on plate 4.

[2]Mountain King is partly a replacement deposit in Paleozoic carbonate rocks.

[3]Location (44°32′17" N., 115°08′13" W.) not labeled on plate 4.

Table 17. Recognition criteria for mixed base- and precious-metal veins (see pl. 4)

Map area	Diagnostic: Presence of base and precious metals	Presence of high-angle planar fractures or faults	Presence of granitic rocks of the Idaho batholith	Presence or proximity of roof pendants	Total	Permissive: Presence or proximity of leucocratic granite	Veins not associated with Tertiary hypabyssal or plutonic rocks	Wall rock alteration near veins	Anomalous metals in stream sediments: Cu	Pb	Zn	Ag	Proximity to productive mines	Proximity to known base metal vein prospects	Total	Resource potential
1	-1	1	1	1	2	-1	1	0	1/2	-1/2	-1/2	1/2	-1	-1	-2	Low
2	1	1	1	1	4	-1	0	1	1/2	1/2	1/2	1/2	1	1	4	High
3	1	-1	1	-1	0	-1	0	0	1/2	0	0	0	-1	-1	-2 1/2	Low
4	1	1/2	1	1	3 1/2	1	-1	0	1/2	1/2	0	1/2	1	1	3	Moderate
5	1	-1	1	-1	0	1	-1	0	1/2	1/2	1/2	1/2	-1	-1	0	Low
6	1	-1	-1	-1	-2	-1	-1	0	0	0	0	0	-1	-1	-4	Low
7	-1	1	1	-1	0	-1	-1	-1	1/2	1/2	1/2	1/2	-1	-1	-3	Low
8	1	1	1	-1	2	-1	-1	0	1/2	0	0	0	-1	-1	-3 1/2	Low
9	1	-1	1	0	1	-1	-1	-1	1/2	1/2	1/2	1/2	-1	1	-1	Low
10	1	-1	1	1	2	1	-1	1	1/2	1/2	1/2	1/2	1	1	5	Moderate
11	1	1	1	1	4	1	-1	1	1/2	1/2	1/2	1/2	1	1	5	High
12	1	1	-1	-1	0	-1	-1	1	1/2	1/2	1/2	1/2	1	-1	1	Low
13	1	1	1	1	4	-1	1	1	1/2	1/2	1/2	1/2	1	1	5	High
14	1	1/2	1	1	3 1/2	-1	-1	0	1/2	1/2	1/2	1/2	-1	-1	-2	Moderate
15	1	1	1	-1	2	-1	-1	0	0	1/2	0	1/2	1	-1	-1	Low
16	1	-1	1	-1	0	1	0	0	1/2	1/2	1/2	1/2	-1	-1	1	Low
17	1	1	1	-1	2	-1	-1	1	1/2	1/2	1/2	1/2	1	1	3	Moderate
18	1	1	1	-1	2	-1	-1	-1	1/2	1/2	1/2	0	-1	-1	-3 1/2	Low
19	1	1	1	-1	2	-1	-1	1	1/2	1/2	1/2	1/2	1	-1	1	Moderate
20	-1	1	1	-1	0	1	-1	0	1/2	1/2	1/2	1/2	-1	-1	0	Low
21	1	-1	1	1	2	1	-1	-1	1/2	1/2	0	0	-1	-1	-2	Low
22	1	1	0	1	3	-1	-1	0	1/2	1/2	1/2	1/2	1	1	2	Moderate
23	1	-1	-1	-1	-2	-1	-1	0	0	1/2	1/2	0	-1	-1	-3	Low
24	-1	1	1	-1	0	-1	-1	0	0	0	0	0	-1	-1	-4	Low
25	-1	1	1	1	2	-1	-1	0	1/2	1/2	1/2	1/2	-1	-1	-2	Low
26	(see text)															None

High potential: areas 2, 11, and 13

Moderate potential: areas 4, 10, 14, 17, 19, and 22

Low potential: areas 1, 3, 5, 6, 7, 8, 9, 12, 15, 16, 18, 20, 21, 23, 24, and 25

Our studies of the Idaho batholith and other plutonic and hypabyssal rocks suggest that they do not host large deposits of base metals. The batholithic area has been prospected extensively, and while many exposures of mineralized rocks have been found, few have been significant. The high scores for areas 2, 11, and 13 reflect our opinion that those are the areas most likely to contain one or more undiscovered deposits similar to those described above. Areas with moderate potential are considered less likely to contain these deposits; deposits are even less likely in areas with low potential. Areas that contain no mapped Idaho batholith have no potential for deposits of this type.

LEAD-SILVER-ZINC-ANTIMONY-TIN VEIN DEPOSITS

By Wayne E. Hall

Lead-silver-zinc-antimony-tin vein deposits were mined extensively for their high silver values during the latter part of the 19th century. They have been mined only intermittently since then for lead and zinc as well as silver. Gold, tin, antimony, and copper may be present and could be significant byproducts. The deposits are predominantly small, discontinuous veins, lenses, and pods of ore that occur in flat to steep-dipping shear zones in black argillite or carbonaceous micritic limestone host rock. Favorable host rocks in the Challis quadrangle are the Paleozoic Salmon River assemblage and the Ordovician(?) Ramshorn Slate.

The vein deposits lie beneath major thrust faults or near regional unconformities and close to several types of intrusive bodies that include a Cretaceous granitoid stock or sill and Eocene dikes or sills of rhyodacite, dacite, or rhyolite. The maximum distance of the lead-silver-zinc vein deposits from an intrusive body is approximately 3.5 mi. Some of the veins that are in micritic limestone host rock are conformable to bedding. These stratiform deposits tend to be higher in zinc, larger, and lower in overall grade than the predominantly lead-silver vein deposits. At the Livingston Mine the higher grade lead-silver ore in the Christmas stope occurs at the intersection of the stratiform zinc-rich Livingston vein and the 40- to 60-ft-thick Scotch dike of rhyolitic composition (fig. 4; Kiilsgaard, 1949).

Production from the lead-silver-zinc vein deposits from the central Idaho black shale belt is estimated at $65 million. Approximately half of this was produced from high-grade, near-surface lead-silver ore bodies mined between 1879 and 1901. Fragmentary records indicate that approximately $10 million of this was mined from lead-silver vein deposits in the black shale belt within the Challis quadrangle. There was little exploration activity in 1980-1984 and no major deposit was being mined.

Table 18 lists the minor element content of ore minerals from the lead-silver-zinc-antimony-tin veins in the black shale terrane and from the Pacific and Beardsley deposits in the carbonate terrane. The samples were drilled from ore specimens, and in some samples the listed mineral is predominant, but some adjacent minerals were included. The Hoodoo mine contains predominantly sphalerite and is low in silver. All the other deposits have high silver values, ranging from 20 to nearly 500 oz per ton. Copper and antimony run high in all the vein deposits in black shale. The Beardsley and Pacific mines, which are in the Bayhorse Dolomite, have moderately high silver values that do not correlate with high copper and antimony values.

The mineralogy of some of the vein deposits was determined using polished section microscopy, scanning electron microscopy, and X-ray diffraction techniques. The silver is present in tetrahedrite, as tiny exsolved silver sulfantimonide inclusions (diaphorite) in galena, and with antimony in solid solution in galena. A small amount of silver is present in Boulder Basin (43°50′ N., 114°31′ W.) as a silver telluride, possibly hessite. It occurs at the grain boundaries between galena and stannite. The mineralogy of six veins in the black shale terrane is shown in table 19.

An evaluation was made of the potential of the lead-silver-zinc-antimony-tin vein deposits as a possible tin resource. Tschanz and others (1974) first recognized the area of anomalous tin in the northern Boulder Mountains through a regional geochemical sampling program carried out for a mineral resource evaluation of the Sawtooth National Recreation Area. Tin occurs in vein deposits in black shale host rocks in a north-south belt 29 mi long and 3 to 4 mi wide, extending from Boulder Basin in the Hailey 1°x2° quadrangle northward to the Livingston mine in the Boulder Mountains. Tschanz and others suggest that there may be 27,000 tons of silver-lead-zinc ore at the Timberline prospect, averaging 0.48 percent tin and locally containing as much as 6 percent tin. The highest tin values given by Tschanz and others (1974, table 7) were an average of chemical, X-ray fluorescence, and atomic absorption tin analyses.

The high tin values shown by Tschanz and others (1974, table 7) indicated that significant resources of tin might occur in veins that cut the carbonaceous sedimentary rocks. We attempted to verify the tin values of the veins but were unable to do so. The author obtained from Tschanz remaining portions of the Timberline sample that previously had been determined to contain 3 percent tin and the Silver Dollar sample that had been determined to contain 6 percent tin (Tschanz and others, 1974, table 7) and resubmitted the samples for analysis. The reanalyzed sample from the Timberline was found to contain 0.6 percent tin and the Silver Dollar sample 1.2 percent tin. T.H. Kiilsgaard, F.S. Fisher, and Michael O′Leary in 1983 resampled the deposits that were reported by Tschanz and others (1974) to contain significant tin values. They attempted to resample the same sample sites, and the analytical findings of their samples are given in table 20. Tin analyses that we obtained (tables 18 and 20) are about one-third the values given by Tschanz and others (1974, table 7). We do not have an explanation for these differences. Our analyses show that deposits that contain anomalous tin values are in the Salmon River sequence or metamorphosed unit 6 of the Wood River Formation. Deposits in the Ramshorn Slate are low in tin. Mineralogy of the ores is given in table 19. The tin is present predominantly as zincian stannite, but a little is present as cassiterite. The higher tin values are present where the ores contain high silver and antimony and, at Boulder Basin (43°50′ N., 114°31′ W.), high gold values. As the veins are narrow, the ore concentrated in rather small shoots, and the metallurgy complicated, these deposits could not be considered a significant tin resource. However, they contain very high silver values, and possibly tin could be recovered as a byproduct of the lead-zinc-silver ore.

Descriptive Model

Ore Body

<u>Size</u>: Pods containing a few tens of tons to veins with strike length as much as 900 ft, pitch length of 1,500 ft, and thickness of 3 to 15 ft.

Table 18. Minor element content of some ore minerals from lead-silver-zinc-antimony-tin veins in the central Idaho black shale terrane and the Bayhorse mining district

[All values in ppm. Analyses are semiquantitative spectrographic determinations made in the U.S. Geological Survey Emission Spectrography Laboratory in Menlo Park, California; project leader, R. Mays. N, not detectable; --, no data]

Sample No.	Mine	Mineral	Ag[1]	As	Bi	Cd	Cu	Pb	Sb	Se	Sn	Te	W	Zn	Au	Analysts
D651	Pacific-------	Galena----	970	<5,000	<200	<30	50	747,000	<1,000	<500	<200	<200		370	--	J. Consul and P. LaMothe, 1984.
T108	Beardsley-----	--do------	1,130	<5,000	<200	49	1,400	840,000	2,400	<500	<200	<200		650	--	Do.
83WH3	--do----------	--do------	1,370	<5,000	700	<30	1,700	728,000	<1,000	<500	<200	<200		170	--	Do.
KR-839C	Cal-Ida-------	--do------[2]	2,360	<5,000	<200	970	4,900	556,000	6,700	<500	3,100	<200		100,000	--	Do.
R-522	Hoodoo--------	Sphalerite	<200	<5,000	<200	5,200	310	<1,000	<1,000	<500	<200	<200		630,000	--	Do.
KR-850C	Clayton Silver	Galena----	1,570	<5,000	<200	80	7,100	752,000	5,500	<500	<200	<200		1,130	--	Do.
83WH35	White Cloud---	Jamesonite	690	13,100	<200	175	400	381,000	393,000	5,200	1,040	280		2,700	--	Do.
KR-820C	Darlin--------	Galena----	1,360	<5,000	<200	<30	510	677,000	2,300	<500	380	<200		25,500	--	Do.
D807	Boulder Basin-	--do------	4,500	<5,000	<200	350	12,400	617,000	20,900	<500	340	<200		6,000	--	Do.
D807D	--do----------	--do------	3,690	<5,000	<200	180	14,500	685,000	29,400	940	300	--		2,000	20	Karen Duvall, 1977.
D807-1	--do----------	--do------	5,000	1,000	N	200	20,000	--	20,000	--	15,000	--		15,000	200	Do.
D807-4	--do----------	--do------	15,000	3,000	20	700	>20,000	--	>50,000	--	12,000	--		--	--	J. Consul, 1984.
83WH36	Silver Dollar-	--do------	6,000	--	--	--	--	--	--	--	6,000	--		--	--	Do.
83WH37	Timberline----	--do------	1,650	--	--	--	--	--	--	--	6,000	--		--	--	

[1]To convert silver to ounces, divide ppm by 34.3.

[2]These analyzed samples were drilled from ore specimens. An effort was made to drill out only one mineral, but the analyses indicate the samples are mixtures of minerals with the listed mineral predominant.

Table 19. Mineralogy of six lead-silver-zinc-antimony-tin veins in the central Idaho black shale terrane

[Mineral identifications made by Robert Felder (microscopy and X-ray diffraction) and Robert Oscarson (scanning electron microscope). M, major (+10%); C, common (3-9%); Mn, minor (1-2%); Tr, trace; blank, not observed]

Mineral	Mine					
	Boulder Basin[1]	Crater Lake[2]	Coffee Pot[3]	Livingston[2]	Stoneboat[4]	White Cloud[2]
Arsenopyrite ($FeAsS$)		Tr	Mn	Mn		Mn
Bornite (Cu_5FeS_4)	Tr					
Bournonite ($PbCuSbS_3$)	Mn					
Cassiterite (SnO_2)	Tr					
Chalcopyrite ($CuFeS_2$)	Tr	Tr		Tr		Tr
Covellite (CuS)	Tr				C	Tr
Galena (PbS)	M		M	C	M	Mn
Jamesonite ($Pb_4FeSb_6S_{14}$)	Mn	M	M	M		M
Magnetite (Fe_3O_4)	C					
Marcasite (FeS_2)		M				
Pyrite (FeS_2)	M		Mn	M	M	Mn
Pyrrhotite ($Fe_{1-x}S$)		M				
Ag-telluride (Ag_2Te)	Tr			Tr		
Sphalerite (ZnS)	M			M		
Stannite (Cu_2FeSnS_4)	Mn			Mn		Mn
Tetrahedrite ($(Cu,Fe)_{12}Sb_4S_{13}$)	C	Tr	Mn	Tr	C	Tr

[1]Located on the Hailey $1^{o}x2^{o}$ quadrangle at $43^{o}50'$ N., $114^{o}31'$ W.

[2]See plate 5.

[3]Located on the Hailey $1^{o}x2^{o}$ quadrangle at $43^{o}54'$ N., $114^{o}38'$ W.

[4]Located on the Hailey $1^{o}x2^{o}$ quadrangle at $43^{o}55'$ N., $114^{o}38'$ W.

Table 20. Atomic absorption analyses of ore samples from base- and precious-metal mines and prospects in the central Idaho black shale terrane

[In parts per million. Analyzed in U.S. Geological Survey laboratory, Denver, Colo.; Randy Hill and T. Roemer, analysts. N, not detected]

Sample No.	Mine	Cu	Pb	Zn	Ag	As	Au	Bi	Cd	Mo	Sb	Sn	Sn	Te	Location
KR818C	Red Robin--------	70	30	18,000	0.5	80	<0.05	N	110	160	5	42	14	0.2	Washington Peak quad.; 4th of July Creek.
KR819C	Darlin-----------	40	4,000	38,000	24	20	.10	N	110	N	2	28	22	1.0	Horton Peak quad.; Grand Prize Gl.
KR820C	--do-------------	230	90,000	1,000	260	60	<.05	N	12	2	27	96	100	.5	Do.
KR822C	Peace of Mine----	760	34,000	118,000	90	160	.05	3	110	3	100	150	310	1.4	Horton Peak quad.; Pole Creek.
KR824C	Coffee Pot-------	10	20,000	900	140	20	<.05	N	4.2	<2	120	8	20	.6	Horton Peak quad.; Gladiator Cr.; Galena.
KR825C	Coffee Pot-------	1,000	52,000	400	770	220	.15	7	5.8	<2	920	720	4,000	90	Horton Peak quad.; Gladiator Cr.; Galena.
KR828C	Stoneboat--------	650	120,000	3,000	160	240	.10	N	38	5	240	320	570	2.3	Do.
KR827C	--do-------------	1,800	17,000	170,000	130	400	.35	N	56	20	200	980	1,500	.9	Do.
KR833C	Hoodoo-----------	20	1,400	600	.6	20	.05	N	1.8	<2	6	<2	10	8.0	Robinson Bar quad.; Slate Cr.
KR836	Tango------------	1,000	2,900	700	10	320	.50	N	20	140	46	24	5,700	.3	Livingston Cr. quad.; Silver Rule Cr.
KR839	Silver Rule------	3,000	430,000	100,000	1,000	2,600	.25	N	130	9	4,200	1,980	1,000	50	Livingston Cr. quad.; Silver Rule Cr.
KR838	--do-------------	760	110,000	4,000	200	600	1.30	N	26	16	680	130	170	60	Do.
KR843C	Ramshorn---------	59,000	130,000	58,000	1,700	7,200	.30	1,160	48	<2	14,100	<2	3	<.2	Clayton 15′ quad.; Bayhorse Cr.
KR844C	--do-------------	8,000	10,000	14,000	620	3,800	.10	160	70	<2	3,700	18	11	<.2	Do.
KR845C	Pacific----------	20,000	45,000	175,000	1,200	80	.4	N	66	28	3,700	<2	2	<.2	Do.
KR846C	Riverview--------	580	1,000	90,000	63	<10	.35	<1	75	<2	140	<2	<2	<.2	Clayton 15′ quad.; Bayhorse Creek.
KR847C	--do-------------	3,000	47,000	190,000	230	80	.70	<1	230	2	940	<2	2	<.2	Do.
KR848C	Clayton Silver[1]--	25,000	250,000	30,000	2,000	9,600	.75	400	33	14	10,200	16	10	.2	Clayton 15′ quad.; Clayton, Id.
KR849C	--do-------------	100	28,000	2,000	1,500	1,600	.15	<1	33	<2	7,000	<2	2	.3	Do.
KR850C	--do-------------	11,000	660,000	30,000	33	20	<.05	<1	16	<2	24	<2	20	<.2	Do.
KR852C	Black Rock-------	70	5,400	300	770	1,000	.55	2,000	92	16	17,000	120	210	30	Washington Pk. quad.; Washington Basin.
KR853C	--do-------------	1,900	150	150	5	10	1.7	66	1	3	65	<2	4	2.5	Do.
KR855C	Yacomella--------	170	34,000	32,000	75	600	.50	900	45	2	8,300	70	30	40	Do.
KR856C	Bible Back-------	1,000	54,000	75,000	430	600	.55	<1	110	<2	2,900	660	450	8.0	Do.
KR857C	Empyreum---------	80	17,000	140	170	24,000	.65	2,720	24	<2	10,000	92	40	100	Horton Peak quad.; Germania Basin.
KR865C	Patty Flynn------	30	150,000	150	110	600	1.40	3	22	2	15,200	74	390	4.0	Washington Peak quad.; Strawberry Basin.
KR866C	Timberline-------	2,000	27,000	62,000	385	500	.65	20	150	9	1,800	80	720	60	Washington Peak quad.; Ants Basin.
KR868C	--do-------------	3,000	180,000	4,000	530	1,000	.75	N	720	3	13,500	140	1,120	60	Do.
KR869C	--do-------------	4,000	110,000	4,000	1,070	1,800	.55	N	760	3	17,500	440	1,200	50	Do.
KR870C	Meadowview-------	500	850	32,000	10	40	<.05	N	330	5	240	3	27	.7	Washington Peak quad.; Fourth of July Cr.
KR872C	Meadowview-------	750	300	190,000	6.6	10	.05	1	980	2	30	<2	2	1	Washington Peak quad.; Fourth of July Cr.
KR873C	Silver Dollar----	5,000	84,000	60,000	1,350	2,600	3.2	1	1.8	15	17,500	440	1,100	60	Washington Peak quad.; Strawberry Basin.
KR876C	White Cloud------	230	90,000	90,000	400	50	<.10	240	870	10	21,000	20	55	100	Do.
KR876AC	Confidence-------	560	180,000	76,000	90	200	.30	30	340	<2	160	17	<2	1.5	Washington Peak quad.; Fourth of July Cr.
KR877C	Rupert-----------	130	130,000	38,000	100	500	.25	25	170	3	100	<2	2	10	Do.
KR878C	Deer Trail-------	870	130,000	92,000	38.4	200	.10	1	380	2	60	<2	<2	.4	Washington Peak quad.; Fourth of July Cr.
KR902C	Livingston-------	2,000	300,000	62,000	52	10,000	1.0	.6	430	7	19,500	200	830	6.5	Livingston Cr. quad.; Jim Creek.
KR903C	--do-------------	240	350,000	1,000	51	14,000	.25	25	48	N	20,000	100	480	40	Do.
KR904C	--do-------------	2,500	320,000	42,000	115	6,400	.70	160	360	2	20,000	100	600	60	Do.
KR905C	--do-------------	1,000	120,000	35,000	100	3,200	.20	2	460	2	13,000	160	880	12	Do.
KR906C	Livingston-------	50	2,900	1,400	78	2,400	.10	<1	22	25	3,500	17	95	1.0	Livingston Cr. quad.; Jim Creek.
KR908C	Little Livingston	1,000	180,000	3,000	104	1,400	60	14	50	7	1,000	12	100	30	Livingston Cr. quad.; Railroad Ridge.

[1]Sample of concentrate from the Clayton Silver mill.

Shape: Small lenses or pods to linear veins but with considerable range in thickness. Sharp contacts with country rock.

Tonnage and grade: From a few hundred to $nx10^5$ tons. Grade ranges from small lenses containing several hundred ounces Ag/ton and 50 percent Pb, to moderate size ore bodies that range from 5 to 45 oz Ag, 5 to 20 percent Pb, 5 to 13 percent Zn, trace to 1 percent Cu, and trace of gold.

Mineralogy

Major ore minerals: Galena, sphalerite, jamesonite, silver-bearing tetrahedrite.

Minor ore minerals: Zincian stannite, cassiterite, silver telluride (hessite?), enargite, bornite, bournonite, chalcopyrite, and various minute silver sulfantimonide inclusions in galena.

Gangue minerals: Quartz, calcite, jasperoid, siderite, pyrite, pyrrhotite, arsenopyrite, siderite.

Major commodities

Major commodities listed in approximately decreasing order of importance: silver, lead, zinc, gold, copper, antimony, tin, cadmium, arsenic.

Character of ore

Mostly massive, fine- to coarse-grained sulfide ore but ranges to disseminated sulfide minerals in a quartz and (or) siderite or calcite gangue or in a sheared carbonaceous host rock.

Weathering products

The veins that are lead-silver- or lead-zinc-silver-rich and contain little pyrite or pyrrhotite gangue have an inconspicuous outcrop. Coarse-grained galena may have a brown cellular iron oxide outer rind and a shiny unaltered galena interior. Both sphalerite and galena can form inconspicuous, fragile gossans that consist of limonite, cerussite, secondary yellow powdery antimony oxides (e.g. bindheimite) and quartz and calcite. Veins with abundant pyrite, pyrrhotite, and arsenopyrite have a dark-brown or reddish-brown gossan outcrop. Much oxide ore from outcropping high-grade lead-silver deposits was mined during the late 19th and early 20th centuries. Some of the heavy gossans from pyrite-rich veins were mined for their gold content, which was a residual enrichment.

Lithology of host rock

Black, siliceous facies argillite, siltite, siltstone, shale, fine-grained quartzite, micritic limestone, and gray sandy limestone. Carbonaceous micritic limestone and black argillite are the most common hosts for ore.

Alteration

Veins are mostly in contact metamorphic zones around calc-alkaline granitic plutons or near large felsic dikes or sills. Siliceous clastic rocks are altered to hornfels; micritic limestone is altered to a tremolite-bearing limestone, calc-hornfels, and locally to skarn.

Geochemical and mineral indicators

Geochemical: Zn, Pb, Sb, As, Ag, Cu, organic carbon

Mineral: Siderite, jasperoid, quartz, calcite, and secondary Zn, Pb, and Sb oxides (hemimorphite, smithsonite, hydrozincite, cerussite, plumbojarosite, bindheimite).

Controlling structures

1. In steep faults and sheared zones below regional thrust faults.
2. Beneath arched or domed thrust faults, especially where there is evidence of doming by buried intrusive.
3. In black shale terrane near an intrusive body.

Geophysical indicators

Most of the deposits in the Challis quadrangle are low on the flank of a magnetic high. The area is not sufficiently large to state categorically that this is true for the whole black shale belt.

Isotopic data

Fluid-inclusion and stable isotope studies of lead, sulfur, and deuterium indicate that the lead and sulfur had a crustal source and that meteoric water was heavily involved in the hydrothermal ore fluid system.

Resource Assessment

From the descriptive model presented above, we have defined three diagnostic criteria and nine permissive criteria.

Diagnostic criteria

1. In a black-shale terrane.
2. Locally anomalous concentrations of lead and zinc.
3. Within 4 mi of a granitic pluton.

Permissive criteria

1. Presence of an overlying regional thrust fault.
2. Presence of gossans.
3. Presence of barite deposits.
4. Evidence of synsedimentary or penesynsedimentary extensional tectonics.
5. Anomalous concentrations of Ag, Sb, Sn.
6. Highly carbonaceous beds in the black shale terrane.
7. Presence of vein siderite or quartz.
8. In Salmon River assemblage or Ramshorn Slate.
9. History of productive base- and precious-metal deposits within the area.

The quadrangle was divided into 15 numbered areas (pl. 5) on the basis of the geologic map, the distribution of productive mines of this type, and maps of the regional geochemistry. The numbered areas range from areas of little potential to areas with high potential for lead-silver-zinc-antimony-tin veins. The first area outlined was the black shale belt, except for a small included area of biotite granodiorite in the vicinity of the Aztec mine. This was done because geochemical maps indicate anomalous concentrations of lead, zinc, and silver in this area; proximity to black shale terrane may be the cause of these anomalous concentrations of base metals. Smaller areas are tightly grouped within the black shale terrane. The large area of the Idaho batholith, area 15, has a low potential because the black shale is absent, except in metamorphic screens. Areas of Challis volcanics, area 13, east and northeast of the black shale belt also have a low potential because of the thick volcanic cover. Area 3, west of the Bayhorse district, has potential for deposits of this type as the volcanic cover is discontinuous and windows of Paleozoic rocks are present. Area 5 is similar because of outcrops of Grand Prize Formation adjacent to the Idaho batholith in the northwest part of the area.

The areal distribution of each of the above criteria was plotted on three maps--one map for diagnostic and two for permissive criteria. The basis for assigning semiquantitative valuation to each area is given previously by

Fisher (this volume, p. 114). The scores for each area are tabulated in table 21.

Our interpretation of the resource potential indicated by these semiquantitative scores is as follows:

High potential: areas 1, 6, and 10

Moderate potential: areas 2, 3, 5, 7, 8, 9, 12, and 14

Low potential: areas 4, 11, 13, and 15

Areas 1, 6, and 10 each have mines that have been productive or have been extensively explored because of outcrops of mineralized rock. Each mine is targeted by geochemical halos of lead, zinc, barium, and silver. Each area is considered to have a high probability for additional ore within the anomalous areas. Within the areas of moderate potential, attention is directed to the anomalous silver and zinc values in the Grand Prize Formation next to the Idaho batholith in area 5. This is the largest area of anomalous values of silver shown by stream-sediment samples in the Challis quadrangle, but no ore is known in the area. Although areas 3 and 4 lie within the region outlined in the black shale terrane, they are a window of the carbonate terrane west of the Ramshorn Slate, and the deposits in the window (Clayton Silver, Rob Roy, and Dryden) are precious-metal rather than base-metal dominant. These deposits are considered by Hobbs and others (this volume, p. 175).

Most of the areas that have been classified as having moderate potential are within the black shale terrane but lie more than 4 mi from a granitic pluton, or they are in black shale terrane within 4 mi of a granitic pluton but no anomalous concentrations of metals were detected from the regional stream-sediment sampling. Areas of low potential are areas underlain by granite or volcanics outside the black shale terrane.

FLUORSPAR VEINS

By Frederick S. Fisher, Kathleen M. Johnson, and S. Warren Hobbs

Fluorspar is a common gangue mineral in many base- and precious-metal veins in the Challis quadrangle. However, it has been produced as ore only from veins in the Gravel Range and Stanley districts. Minor, nonproductive fluorspar veins are also found in the Marble Creek, Pungo Creek, Aparejo Creek, and Yankee Fork areas (pl. 6).

At Meyers Cove in the Gravel Range district (pl. 1), fluorspar deposits are tabular veins paralleling fracture zones, with some stringers and lenses cutting obliquely across the zones (Anderson, 1943a; Cox, 1954). The deposits are within a northeast-trending belt one-half mile wide and two miles long. They form well-defined lodes along the fractures, generally with minor replacement and some disseminated ore in the adjacent host rock. Individual lodes may be a few tens to hundreds of feet long and up to ten feet wide.

The ore minerals are fluorite with or without minor stibnite in a gangue of barite, calcite, and chalcedony. Average grade of the lodes is 50 percent CaF_2 (Cox, 1954). Host rocks are the 47- to 48-m.y.-old tuffs of Camas Creek. Several small felsite porphyry and lamprophyre dikes are present in the vicinity of the ore bodies.

From 1951 to 1953, 37,432 tons of fluorspar ore were produced from the Meyers Cove deposits. This ore yielded 10,978 tons of acid grade, 998 tons of ceramic grade, and 100 tons of metallurgical grade fluorspar (Anderson, 1954b). From 1954 to 1972 the mines were worked intermittently by the Seaforth Mining Company, and an additional 25,000-30,000 tons of metallurgical

Table 21. Recognition criteria for lead-silver-zinc-antimony-tin vein deposits (see pl. 5)

	Diagnostic				Permissive										
Map area	Black shale terrane	Anomalous Pb and Zn	<4 miles from granitic pluton	Total	Regional thrust fault	Gossan	Barite deposits	Extensional tectonics	Anomalous Ag, Sn Sb	Highly carbonaceous host	Vein siderite or quartz	Pzsr or Or host	Productive deposit	Total	Resource potential
1	1	1	1	3	1	1	0	0	1	1	1	1	1	7	High
2	1	1/2	-1	1/2	1	0	0	0	0	1	0	1	-1	2	Moderate
3	0	1	0	1	1	1/2	0	0	1	1/2	1	-1	1	4	Moderate
4	0	0	0	0	0	0	0	0	0	-1	0	-1	-1	-3	Low
5	1/2	1/2	1/2	1 1/2	0	0	1/2	1	1/2	1/2	0	0	-1	1 1/2	Moderate
6	1	1	1	3	1	1/2	0	0	1/2	1	1	1	1	6	High
7	1	1	-1	1	1	0	0	0	1	1	0	1	0	4	Moderate
8	1	0	1/2	1 1/2	0	1/2	0	0	1/2	1	1/2	-1	1/2	2	Moderate
9	1	0	1	2	1	0	0	0	0	1	0	-1	-1	0	Moderate
10	1	1	1	3	1	1	0	0	1	1	1	1	1	7	High
11	-1	-1	0	-2	-1	0	0	0	-1	-1	0	-1	-1	-5	Low
12	1	0	1	2	1/2	0	0	0	0	1/2	1	0	1	3	Moderate
13	-1	-1	-1	-3	-1	0	0	0	0	-1	0	-1	-1	-4	Low
14	1	0	0	1	1/2	0	0	0	0	1	0	1	-1	1 1/2	Moderate
15	-1	-1	0	-2	-1	0	0	0	1/2	-1	0	-1	-1	-3 1/2	Low

grade ore was produced (John McClung, oral commun., 1985). The mines have been inactive since 1972.

In the Stanley district, fluorspar is present in individual veins as much as 3 ft wide, and as veins and stringers the composite width of which is as much as 15 ft. The deposits are associated with northeast-trending faults and shears and are spatially related to rhyolite dikes. The veins are mostly open-space filling with minor replacement. Two main mineral assemblages are present in the veins: a quartz-pyrite-gold-fluorite assemblage and a quartz-fluorite assemblage. Gold values range from trace to 0.27 oz per ton. Silver ranages from trace to 1.5 oz per ton (Tschanz and others, 1974, p. 591). Chip samples of veins exposed on the Giant Spar claims near the mouths of Big and Little Casino Creeks along the Salmon River assayed 46.2, 55.37, 86.1, and 87.3 percent CaF_2. Samples of veins on the Homestake claims, southwest of the Giant Spar veins, assayed 33.6 percent CaF_2. Dump material from the Gold Chance claims on the east side of Big Casino Creek yielded 45 percent CaF_2 (Tschanz and others, 1974). Host rocks for all the fluorspar deposits near Stanley are granodiorite and granodiorite porphyry of the Idaho batholith. Production of fluorspar from the Stanley district is minor, consisting of a few truckloads shipped during the mid 1940s (Choate, 1962). Drilling in the Casino Creek area indicates a potential of 200,000 tons of fluorspar ore with a fluorite grade of 20-30 percent CaF_2 (Tschanz and others, 1974, p. 221).

Fluorspar veins elsewhere in the Challis quadrangle are generally small. In the vicinity of the Middle Fork Salmon River, on Pungo, Marble, and Aparejo Creeks, veins are about 1 ft wide and exposed lengths are 20 to 700 ft. Host rocks are Tertiary granitic and dioritic rocks. Vein mineralogy is quartz, calcite, and fluorspar (Cater and others, 1973). In the Yankee Fork district, near Loon Creek summit (44°28′ N., 114°44′ W.), veins, stringers, and breccia fillings of fluorspar occur along a northeast-trending zone 1 mi long and several hundred yards wide. Individual veins range in width from 1 in. to 4 ft, averaging less than 1 ft, and have strike lengths of a few hundred feet. Chip samples assayed 49.2 and 39.4 percent CaF_2. Gangue minerals are calcite, chalcedony, and quartz. Base and precious metals are absent and trace amounts of BeO have been reported (Choate, 1962).

Descriptive Model

Ore Body

<u>Size</u>: Veins with ore shoots 1-20 ft wide and up to 900 ft long. Veins may occur in zones up to one-half mile wide and two miles long.

<u>Shape</u>: Lenses, pods, planar veins, and aggregates of veinlets. At times crosscutting but mostly parallel. Some breccia deposits. Veins are mostly open-space fillings with minor replacement.

<u>Tonnage and grade</u>: Grades are variable, ranging from a few percent to over 85 percent CaF_2. Deposits range from a few tons to lodes containing thousands of tons. Grades within individual lodes can be highly irregular.

Mineralogy

<u>Ore minerals</u>: Fluorspar; gold and silver in some deposits in the Stanley district.

<u>Gangue minerals</u>: Barite, chalcedony, quartz, calcite, minor pyrite, and stibnite.

Commodities

Major commodities produced are fluorspar and gold.

Character of ore

Ore lodes are discontinuous along the vein structures. Ores are banded, crustiform, and vuggy. Open-space filling was the predominant form of mineralization, with minor amounts of replacement of wall rocks. Ores include fine, grainy textures, well-formed large crystals, massive aggregates, and breccia fillings. Fluid-inclusion studies suggest homogenization temperatures of 160 °C at Meyers Cove, 150 °C in the Stanley district, and 130 °C in the Yankee Fork district. Salinities were low in all three areas (Constantopoulos, 1985).

Lithology of host rocks

Host rocks in Meyers Cove are the tuffs of Camas Creek-Black Mountain (Fisher and others, 1983), a thick section of welded ash-flow tuffs of Eocene age. These tuffs are mostly red, red brown, or reddish gray and contain variable amounts of small phenocrysts of plagioclase, alkali feldspar, biotite, hornblende, pyroxene, and quartz.

Host rocks in the Stanley district are Cretaceous granodiorite and granodiorite porphyry of the Idaho batholith. These rocks are gray to light gray, medium to coarse grained, and equigranular to porphyritic. Rocks mapped as porphyritic are medium to coarse grained and contain megacrysts of pink potassium feldspar from 3 to 10 cm in length.

Geochemical and mineral indicators

Sediments from streams that are eroding some vein fluorspar deposits are enriched in molybdenum, gold, and silver. Panned concentrates of those sediments may contain tin.

Ore controls

Productive fluorspar deposits are found associated with or along northeast-trending fault and fracture systems. These structures are part of the trans-Challis fault system. In the Stanley district, most veins are spatially associated with rhyolite dikes. In Meyers Cove, small Tertiary dikes of lamprophyre and felsite porphyry occur within and adjacent to the ore zones. Productive deposits are located near the junction of bounding faults of volcanotectonic grabens and graben hinge zones.

Resource Assessment

From the descriptive model above, we define seven recognition criteria, of which three are diagnostic and four are permissive.

Diagnostic criteria

1. Presence of planar high-angle faults or fractures.
2. Evidence of fluorspar mineralization.
3. Proximity to Tertiary hypabyssal intrusions.

Permissive criteria

1. Proximity to trans-Challis fault system. All of the major producing vein fluorspar deposits lie within the trans-Challis fault system. For this reason, areas within the trans-Challis fault system are considered most favorable. Areas less than 5 mi outside the trans-Challis fault system are considered somewhat less favorable.
2. Elevated concentrations of molybdenum, gold, and silver in stream sediments.
3. Tin in panned concentates of stream sediments.
4. Proximity to junctions between graben-bounding faults and graben hinge zones.

Considering the diagnostic criteria, the quadrangle was divided into 18 areas (pl. 6) which were then ranked for their potential for vein fluorspar resources (table 22). Two areas (9, 14) were ranked as having high potential; four areas (6, 8, 12, 13) as having moderate potential; and the remaining 12 as having low potential.

In area 9, the Seaforth Mining Company estimates that 1,000,000 tons of fluorspar ore with an average grade of approximately 35 percent CaF_2 remains to be mined on their property (John McClung, oral commun., 1985). Fluorspar veins assaying at least 30-50 percent CaF_2 are widespread throughout area 9. It is our opinion that with adequate exploration additional resources of the same magnitude could be delineated.

In area 14 the U.S. Bureau of Mines estimated that 200,000 tons of fluorspar ore with a grade of 20-30 percent CaF_2 exists in the Casino Creek deposits. Well-developed structures with associated fluorspar veins of favorable grades are present elsewhere within area 14. Several tens of thousands to a few hundred thousand tons of additional ore may be contained in these deposits.

The Bayhorse fluorspar district (area 12, pl. 6) contains large resources of fluorspar. These ores are classified as stratabound, stratiform breccia-controlled deposits in carbonate rocks and are evaluated by Hobbs (this volume, p. 189).

In areas ranked as having moderate potential, there is only a small probability that economically productive vein fluorspar deposits exist. Such deposits, if present, will be similar to the Pungo Creek deposit, which contains an estimated 26,000 tons of CaF_2 (Cater and others, 1973, p. 353).

In areas of low resource potential, we believe that there are few, if any, vein fluorspar deposits.

URANIUM VEINS

By Kathleen M. Johnson and Theresa M. Cookro

Uranium veins occur in the Idaho batholith northeast of Stanley, in the Basin Creek area. Pitchblende occurs as monomineralic stringers and in veinlets both with and without quartz gangue. Between 1958 and 1960, production from the Hardee, Lightning #2, and Lightning Upper Pit properties (pl. 7) totalled 789 tons of ore at 0.18 percent U_3O_8, yielding 2,840 pounds of U_3O_8 (Wopat and others, 1980, p. 25). Choate (1962) reports that approximately 30 tons, at 0.3-0.4 percent U_3O_8, were stockpiled.

Veins containing radioactive material are also found on the Middle Fork Salmon River, at the Sullivan uranium prospect. This property is described by Cater and others (1973) as occurring in sheared Tertiary granite and dolomitic marble of unknown (but probably Precambrian) age. Minerals recognized in two shear zones include gray sugary quartz, pyrite, fluorite, arsenopyrite or pyrrhotite, thorite(?), chalcopyrite, azurite, and malachite. Cater and others estimate that the prospect contains 23,000 tons of mineralized rock at 0.004 percent U_3O_8 and 800 tons at 0.024 percent U_3O_8, for a total of about 2,000 lbs U_3O_8. Wopat and others (1980) attribute the anomalous radioactivity to the presence of thorium and report 0.39 percent thorium and 0.009 percent U_3O_8.

Because of differences in vein mineralogy and host rocks, we consider the veins on the Middle Fork to be a different deposit type than those at Basin Creek. We do not have enough information about veins like those on the Middle Fork to make a complete assessment and so mention them here for readers

Table 22. Recognition criteria for fluorspar veins (see pl. 6)

Map area	Diagnostic criteria: Planar high-angle faulting	Evidence of fluorspar mineralization	Tertiary hypabyssal intrusives	Total	Permissive criteria: Proximity to trans-Challis fault system	Mo, Au, Ag in stream sediments	Tin in panned concen-trates	Proximity to fault-hinge junctions	Total	Resource potential
1	1/2	0	0	1/2	-1	1/2	1/2	-1	-1	Low
2	1	0	0	1	-1	1/2	1/2	-1	-1	Low
3	1/2	0	0	1/2	-1	1/2	1/2	-1	-1	Low
4	1	0	0	1	-1	0	0	-1	-2	Low
5	1	0	1/2	1 1/2	-1	1/2	1/2	-1	-1	Low
6	1	1/2	1	2 1/2	-1	0	0	-1	-2	Moderate
7	1/2	0	1	1 1/2	1/2	0	1/2	1/2	1 1/2	Low
8	1/2	1	1/2	2	-1	0	0	-1	-2	Moderate
9	1	1	1	3	1	1/2	1/2	1	3	High
10	1	0	0	1	1/2	1/2	1/2	1/2	2	Low
11	1	0	1/2	1 1/2	1/2	1	1	1/2	3	Low
12	1	1	0	2	-1	1	1/2	-1	- 1/2	Moderate
13	1	1/2	1	2 1/2	1	1/2	1/2	1	3	Moderate
14	1	1	1	3	1	1/2	1/2	1	3	High
15	1/2	0	1/2	1	1/2	1	1/2	1/2	2 1/2	Low
16	1	0	1	2	1	1/2	1	1/2	3	Low
17	1/2	0	1/2	1	1/2	1/2	1/2	-1	1/2	Low
18	1/2	0	0	1/2	1/2	1/2	1	-1	1	Low

interested in veins with radioactive minerals. The following description and assessment are based on the deposits at Basin Creek.

Descriptive Model

Ore Body

Size: $nx10^2$ ft long; $nx10^2$ ft wide

Shape: lenticular, irregular, tabular

Tonnage: up to $nx10^4$ tons of ore at average grade of 0.X percent U_3O_8

Mineralogy

Uranium ore minerals: Uraninite (mostly as pitchblende), uranophane, meta-autunite, rare coffinite and brannerite (Wopat and others, 1980)

Other metallic minerals: Pyrite, chalcopyrite, stibnite, galena, sphalerite, molybdenite, gold, silver

Gangue: Quartz, muscovite, iron oxides

Character of ore

Pitchblende occurs as monomineralic stringers and in veinlets, often with quartz and chalcedony. Stringers range in thickness from a fraction of a millimeter to 1 inch (Choate, 1962, p. 30).

Lithology of host rocks

These veins are found in medium- to coarse-grained biotite granite and porphyritic biotite granite of the Cretaceous Idaho batholith. Dikes of Tertiary age, ranging in composition from rhyolite to dacite, intrude the biotite granite and the overlying Tertiary Challis Volcanic Group.

Controlling structures and other features

1. Mineralized veins commonly occur at the intersection of aplitic or pegmatitic dikes and steeply dipping fractures and joints.
2. Ore is concentrated in fractures, stringers, or veinlets and is seldom disseminated in the host rock.

Geochemical and mineralogical indicators

Geochemical: Mineralized rocks are enriched in Ag, As, Mo, Pb, Sb, Y, and Zn relative to unmineralized batholith rocks.

Mineralogical: Quartz, chalcedony, chlorite

Resource Assessment

From the descriptive model above, we define seven recognition criteria, of which we consider four to be diagnostic and three to be permissive.

Diagnostic criteria

1. Presence of medium- to coarse-grained biotite granite.
2. Presence of aplitic or pegmatitic dikes.
3. Presence of steeply dipping to vertical fractures and joints.
4. Evidence of uranium mineralization. This may be known mines and prospects or presence of uranium in stream sediments.

Permissive criteria

1. Evidence of hydrothermal alteration, such as silicification, argillization, or chloritization.
2. Areas of silicified gouge and microbrecciation.
3. Presence of some combination of anomalous Ag, As, Mo, Pb, Sb, Y, and Zn.

Based on these criteria, we divided the quadrangle into 20 types of areas (pl. 7), scored each (table 23), and ranked each for its potential for more deposits of the type described above. Our interpretation of the resource potential of these areas is as follows:

High potential: areas 15 and 19

Moderate potential: areas 6, 8, 10, and 18

Low potential: areas 1, 2, 3, 4, 5, 7, 9, 11, 12, 13, 14, 16, 17, and 20

We believe that areas 15 and 19 have a reasonable chance of having one or more deposits of the type described above. The potential for similar deposits in areas 6, 8, 10, and 18 is lower, perhaps of the order of one deposit somewhere in all five areas. Those areas listed as having low potential have little likelihood of containing undiscovered uranium veins.

TUNGSTEN VEIN AND REPLACEMENT DEPOSITS

By Theresa M. Cookro, S. Warren Hobbs, and Wayne E. Hall

Examples of tungsten vein and replacement deposits and occurrences are the Yellow Pine, West End, Meadow Creek, Quartz Creek (Skipper), Golden Gate and Merry Blue mines, and the Sulfide #10 prospect (pl. 8). The Yellow Pine and Meadow Creek mines produced 831,829 units WO_3, 101,437 oz gold, 14,981 tons of antimony, and 592,211 oz silver (Cooper, 1951). The West End mine produced 66,000 oz Au and 30,000 oz Ag from 1982 to 1985 (Mike Wolfard, written commun., 1984). The Quartz Creek (Skipper) mine produced about 5 tons of 15 percent WO_3 and about 800 lbs of 60 percent WO_3 concentrates in the 1950's (Petersen, 1984). An estimated 300 units WO_3 were produced in the early 1980's (Leonard, oral commun., 1985). The Merry Blue mine produced 7,900 oz of gold (H. Nickelson, written commun., 1953).

The tungsten vein and replacement mines and prospects are located in the northwestern part of the Challis quadrangle along large north-trending fault zones that cut the Idaho batholith and in places wedges of metamorphic rocks. The Middle Fork, South Fork, Boise Ridge, and Deadwood faults (fig. 1) are some of those north-trending faults. Other faults of this type include those that extend along Johnson Creek, Quartz Creek, and Meadow Creek near the townsite of Yellow Pine (Fisher and others, in press). These faults have a strong shear component and some are upthrown on the west as much as 1,500 ft (Kiilsgaard and Lewis, 1985).

Our descriptive model is derived from field observations and the following reports: Kiilsgaard and Lewis (1985), White (1940, 1946), White (unpublished report, 1942), Cooper (1951), Leonard (in press), Currier (1935), Cookro (1985), Cookro and Petersen (1984), Petersen (1984), Petersen and Cookro (1984), Callahan and others (1981a), and Shenon and Ross (1936).

Descriptive Model

Ore Body

Size: $nx10-nx10^2$ ft wide; $nx10^2-nx10^3$ ft long; $nx10-nx10^2$ ft thick

Shape: irregular, fault controlled

Tonnage and grade: $nx10^3$ - $nx10^6$ tons at 2-5 percent WO_3, 0.05-6 percent Sb, 0.01-0.10 oz/ton Au, 0.01-0.20 oz/ton Ag

Mineralogy

Ore minerals: Scheelite, ± wolframite, stibnite, gold, and silver

Gangue minerals: Arsenopyrite, quartz > calcite > vein feldspar > chlorite, epidote

Table 23. Recognition criteria for uranium veins (see pl. 7)

Map area	Diagnostic criteria: Presence of biotite granodiorite	Presence of aplitic or pegmatitic dikes	Presence of steep fractures or joints	Evidence of uranium mineralization	Total	Permissive criteria: Hydrothermal alteration	Areas of silicified gouge	Geochemical anomalies	Total	Resource potential
1	-1	1/2	1/2	-1	-1	1/2	1/2	-1	0	Low
2	1	1/2	1/2	-1	1	1/2	1/2	-1	0	Low
3	1/2	1/2	1/2	-1	1/2	1/2	1/2	1	2	Low
4	-1	0	1	-1	-1	0	0	1	1	Low
5	-1	1/2	1/2	1	1	0	0	-1	-1	Low
6	1	1/2	0	1/2	2	0	0	1/2	1/2	Moderate
7	-1	1/2	1/2	-1	-1	0	0	1	1	Low
8	1	0	1	1/2	2 1/2	0	0	-1	-1	Moderate
9	-1	0	0	1/2	- 1/2	0	0	1/2	1/2	Low
10	1	0	1/2	1	2 1/2	1/2	0	-1	- 1/2	Moderate
11	-1	1/2	1	-1	- 1/2	0	0	1	1	Low
12	-1	1/2	1	-1	- 1/2	1	1/2	1	2 1/2	Low
13	-1	0	1	-1	-1	1	1/2	1	2 1/2	Low
14	1	0	1/2	-1	1/2	0	0	1/2	1/2	Low
15	1	1	1	1	4	1	1	1	3	High
16	1	0	0	-1	0	1/2	0	1	1 1/2	Low
17	1	1/2	1/2	-1	1	1/2	1/2	1	2	Low
18	1	1/2	1	-1	1 1/2	1/2	1/2	1	2	Moderate
19	1	1/2	1/2	1	3	0	0	-1	-1	High
20	-1	1/2	1/2	-1	-1	1/2	1/2	1/2	1 1/2	Low

Minor minerals: Pyrite > sphalerite > chalcopyrite > tetrahedrite > galena, fluorite ± cinnabar

Commodities

Tungsten, antimony, gold, and silver

Alteration

The rock is strongly brecciated, silicified, and sericitized. Clay minerals resulted from the intense brecciation and alteration of feldspars. Manganese oxides are ubiquitous and scorodite is sometimes present. The altered granodiorite is much more fine grained due to the influx of secondary silica. In the shear zones the rock is lighter in color, biotite has been removed, and the feldspars have been leached or altered to clay. The sheared country rock in the vicinity of the deposits is commonly vuggy with chalcedonic quartz and euhedral quartz crystals lining cavities. At the Golden Gate and Quartz Creek mines the miners followed the manganese oxides to find higher grade tungsten ore.

The extent of brecciation is best observed by using ultraviolet light which reveals several stages of fracturing and brecciation identified by infillings of quartz and scheelite.

Character of the ore

1. Fissure-filling quartz veins and veinlets that form a stockwork pattern.
2. Movement along the faults is post mineral.
3. Scheelite localized by carbonate-rich inclusions in the Idaho batholith.

Also remobilized calcite is preferentially replaced by scheelite over calcite in the metasedimentary carbonate inclusions.

Lithology of the host rocks

Altered granitic rocks of the Cretaceous Idaho batholith and altered carbonate-rich metasedimentary inclusions in the batholith.

Controlling structures and other features

1. The stockworks are in batholithic terrane commonly associated with brecciated carbonate-bearing metasedimentary inclusions along regional north-trending faults, which may be several miles long and often several hundreds of feet wide.
2. Mineralization was best developed within the main north-trending shear zones at the junction with eastward-branching splits. Westward splits in most cases are barren. At the Quartz Creek mine the east-trending faults have an extensional component, whereas the west-trending faults have a compressional component.

Geochemical and mineral indicators

Sb, As, Au, Ag, silica flooding, sericite, and clay minerals.

Resource Assessment

From the descriptive model, we define eleven recognition criteria; four are diagnostic and seven are permissive.

Diagnostic criteria

1. Secondary silica enrichment
2. North-trending fault zones
3. Plutonic rock present
4. Presence of tungsten minerals or geochemical anomalies of tungsten

Permissive criteria

1. Branching easterly faults N. 30^{o}-60^{o} E.
2. Carbonate metasedimentary inclusions
3. Sericite
4. Argillically altered rocks
5. Manganese oxides
6. Known occurrences of or chemical anomalies of Sb
7. Known occurrences of or chemical anomalies of As

The quadrangle was divided into nine numbered areas (pl. 8) based on various combinations of known or suspected criteria and on available data. The scores for each area are listed in tabular form on table 24.

Our subjective interpretation of the resource potential of the different areas as indicated by these scores, is as follows:

High potential: 1 and 3
Moderate potential: 4, 8, and 9
Low potential: 2, 5, 6, and 7

The meaning of these evaluations can be better expressed qualitatively than quantitatively or statistically. Qualitatively, the available data indicate that areas 1 and 3 should have top priority as target areas in prospecting for vein and replacement tungsten deposits. We believe that areas of high potential contain at least one additional ore deposit comparable to the descriptive model in areas 1 and 3. The combinations of recognition criteria in areas 4, 8, and 9 are sufficiently compelling to indicate a lower but significant probability that one additional ore deposit comparable to the descriptive model occurs in each area. And, finally, the probability of a deposit of this type in areas 2, 5, 6, and 7 is quite small.

MANGANESE REPLACEMENT VEINS

By Thor H. Kiilsgaard

Manganese minerals occur in small amounts in many Challis quadrangle deposits, but at no known occurrence are they present in sufficient quantity to be considered as a potential resource of manganese.

Base- and precious-metal veins in the area commonly show thin dendritic films or coatings of black manganese oxide on fracture surfaces, and sometimes they contain small pockets a few inches in maximum dimension of dark-brown to black, earthy, manganiferous material known as wad. Both the black manganese oxide coating and the wad are near-surface oxidation products, usually from rhodochrosite, manganiferous siderite, ankerite, or one of several other primary minerals that contain minute amounts of manganese.

The most extensive evidence of manganese mineralization in the quadrangle is a northeast-trending belt of highly altered Eocene granite that crosses the divide northwest of Mt. Cramer in the Sawtooth Range in the Sawtooth Wilderness. The belt is about 1,000 ft wide and 3 mi long. Manganese oxide along fractures in the altered granite is conspicuous, but freshly broken rock shows the oxide to be only a stain. Nine samples taken from the area contained from 300 to 5,000 ppm Mn, a content far too low to be considered as a resource.

Southwest of Mt. Cramer, in the headwaters area of Hidden Lake, is a large vein that strikes N. 80^{o} E., dips 70^{o} NW, and may be traced for several hundred feet along strike. Discontinuously along the vein are lenses of black manganese-coated vein material as much as 20 ft wide and 40 ft long. A chip sample across a 10-ft interval of the largest lens contained 1.8 percent

Table 24. Recognition criteria for tungsten vein and replacement deposits (see pl. 8)

Map area	Diagnostic criteria: Secondary silica enrichment	North-trending fault zone	Plutonic rock	Tungsten minerals or geochem.	Total	Permissive criteria: Branching easterly faults	Carbonate inclusions	Sericitic altera-tion	Argillic altera-tion	Manganese oxides	Sb in geochem. or mineral occurrence	As in geochem. or mineral occurrence	Total	Resource potential
1	1	1	1	1	4	1/2	1	1	1	1	1	1	6 1/2	High
2	0	1/2	1	1/2	2	1/2	1/2	0	0	0	-1	1/2	1/2	Low
3	1	1	1	1/2	3 1/2	1/2	1/2	1	1/2	1/2	1/2	1/2	4	High
4	1/2	1/2	1	1	3	0	1/2	1/2	0	0	1/2	1/2	2	Moderate
5	1/2	-1	1	1	1 1/2	1/2	1/2	1	1	1/2	-1	1/2	3	Low
6	1	-1	-1	1/2	- 1/2	1/2	-1	0	1	0	0	1/2	1	Low
7	1/2	1	-1	1	1 1/2	1/2	1/2	-1	-1	0	1/2	1/2	0	Low
8	1/2	1/2	1	1/2	2 1/2	1/2	1/2	1/2	1/2	0	1/2	1/2	3	Moderate
9	1/2	1/2	1/2	1/2	2	1/2	1/2	0	1	0	0	1/2	2 1/2	Moderate

manganese, and a nearby sample taken across a 20-ft width of the lens contained 4.9 percent manganese (Kiilsgaard and others, 1970, p. D113). The manganese oxide along the vein and lenses is a coating that does not penetrate into the freshly broken Eocene ganite. The manganese coating probably is an oxidation product from rhodochrosite. Rhodochrosite in veinlets ranging from 1 to 4 in. thick crop out upstream from the large vein, and they or similar veinlets could have supplied the manganese oxide that has stained the surface exposures.

Rhodochrosite in veinlets ranging from 1/4 to 1 in. thick also are reported at the Old Timer prospect, which is 1 mi east of Sheep Mountain in the north-central part of the quadrangle (Cater and others, 1973). The amount of rhodochrosite is negligible, and the deposit should not be considered as a potential resource of manganese.

SEMIPRECIOUS OPAL VEINS

By Frederick S. Fisher

Semi-precious opal occurs in small veins and veinlets filling fractures in the Sunnyside tuff near Grays Peak (44°50′ N., 115°04′ W.). The opal veinlets occupy a limonite-stained zone approximately 1 mi long and 50 to 100 ft thick below an obsidian-bearing rhyolite (Cater and others, 1973, p. 371). Other opal occurrences are reported near the confluence of Panther Creek and Opal Creek (44°54′ N., 114°19′ W.) and on a tributary of the South Fork of Camas Creek (44°44′ N., 114°33′ W.) (Ross, 1927, p. 20). In all of these occurrences the opals are mostly brittle and not of gem quality. We believe that there is little or no resource potential for semiprecious opal deposits in the Challis quadrangle.

CRETACEOUS MOLYBDENUM STOCKWORKS

By Wayne E. Hall

The stream-sediment regional geochemistry map for molybdenum in the Challis quadrangle (K.M. Johnson, written commun., 1984) shows anomalous concentrations of the metal in the following geologic environments: (1) at the southwest end of the trans-Challis fault system associated with northeast-striking Tertiary felsic plutons cutting the Idaho batholith (CUMO, Little Falls); (2) in molybdenum stockwork deposits within compositionally zoned Cretaceous biotite granodiorite stocks (Thompson Creek, Cabin Creek); (3) in molybdenum stockwork deposits in skarn adjacent to and within Cretaceous biotite granodiorite stocks (Little Boulder Creek, Baker prospect); (4) in carbonaceous black shale terrane in the Slate Creek lineament; (5) near Wolf Mountain (44°01′ W., 115°25′ N.) east of the Banner mine in an area of small leucogranite plutons intruded into Cretaceous biotite granodiorite (no known prospects); and (6) in fractures and disseminations in hydrothermally altered zones in the Sawtooth batholith in the vicinity of Rock Creek (south of the Challis quadrangle; 43°55′ N., 115°02′ W.) and Cramer Lake (44°02′ N., 114°59′ W.). The Tertiary molybdenum occurrences in the trans-Challis fault system and in the Sawtooth batholith (items 1 and 6 above) are discussed by Kiilsgaard and Bennett (this volume, p. 158). The Cretaceous occurrences are discussed here.

The central part of the Challis quadrangle on the east side of the Idaho batholith lies within a Late Mesozoic-Tertiary magmatic arc in the western

North American Cordillera, extending from southeast California to southeast Alaska, that hosts many economically significant molybdenum stockwork deposits (Theodore and Menzie, 1984). These deposits are associated with fluorine-deficient I-type compositionally zoned granitoid plutons that are probably subduction related. Two large, well-known molybdenum stockwork deposits associated with Cretaceous granitoid stocks lie in the Challis quadrangle within this magmatic arc, and several other prospects are known (pl. 9). The Thompson Creek deposit, the only deposit that is being mined (as of 1985), is a molybdenum stockwork within a compositionally zoned granite stock of biotite granodiorite and porphyritic biotite granite (Hall and others, 1984). The stock is elongate in a northwest-southeast direction and is at least 1.5 mi long and 0.5 mi wide. Both the biotite granodiorite and porphyritic biotite granite are cut by small plutons of leucogranite. The chemical composition of the stock is given by Hall and others (1984). The following is a description of the mineralization of the Thompson Creek deposit from Hall and others (1984):

> "Molybdenite stockwork occurs within the Thompson Creek intrusive complex in an elongate tabular body that trends N. 45° W. and plunges 23° NW. The mineralized area is about 11,100 ft long by 3,000 ft wide, and the minable ore body is 4,500 ft long, 1,900 ft wide, and 2,200 ft thick. Molybdenite within this zone occurs primarily in coarse quartz-biotite-potassium feldspar-white mica veins that trend N. 45°-60° W. and dip 60°-80° NE. The molybdenite occurs as coarse rosettes within quartz veins, as flakes interleaved with coarse-grained secondary white mica or biotite within or at the margins of veins, and as high-grade vein selvages. Vein thicknesses range from 0.2 to 5 cm and vein frequence ranges considerably within the ore zone. Sulfide minerals other than molybdenite are scarce."

Mineralization at Thompson Creek is Late Cretaceous. Two samples of secondary muscovite from molybdenite-bearing pegmatitic pods were dated by the Ar^{40}/Ar^{39} method as 87.35±0.43 and 87.58±0.31 m.y. (L.W. Snee, written commun., 1985).

The Thompson Creek deposit has low concentrations of rhenium. Molybdenite from a bulk sample from the exploration adit contained 15.6 ppm Re, and pyrite contained 5 ppb (Jean Mark Luck, written commun., 1983). Locally the Thompson Creek ore contains silver. A sample of silicified, carbonaceous molybdenite ore collected in the open pit near the contact with the Salmon River assemblage contained 270 ppm silver (7.9 oz/ton)*. The silver apparently is in the carbonaceous matter, but the form is not known.

The molybdenum stockwork deposit at Little Boulder Creek in the White Cloud Peaks lies within a downdropped belt of contact-metamorphosed fine-grained limy sandstones of unit 6 of the Wood River Formation on the east side of the Cretaceous White Cloud stock (pls. 1 and 9). The deposit has been mapped and studied by Cavanaugh (1979). The tactite zone is bounded on the west by a steep N. 10° E.-striking fault that is down-dropped on the east. The fault passes along the foot of the steep face on the west side of Baker Lake. The tactite zone is bounded on the east by the Uncle Jess fault, which is a steep fault striking N. 30° E. and brings the tactite on the northwest against Challis Volcanic Group on the southeast. The White Cloud stock is

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*Analyzed by emission spectroscopy by J. Consul under the direction of R. May, U.S. Geological Survey, Menlo Park, Calif.

compositionally zoned from equigranular biotite granodiorite on the border to coarsely porphyritic biotite granite in the interior. The biotite granite contains abundant metacrysts of microcline as large as 3 cm, and the granite is cut by abundant feldspar and quartz-feldspar veins. Two ore bodies are exposed at Little Boulder Creek. The north, and best exposed, ore body is about 300 m northeast of Baker Lake on the east side of the Little Boulder Creek stock--a small N-S elongate stock 1,395 ft long and 820 ft wide that lies 985 ft east of the White Cloud stock. The north ore body is spatially and probably genetically related to the Little Boulder Creek stock. The Little Boulder Creek stock ranges texturally in the same outcrop from fine- to medium-grained equigranular biotite-amphibole granodiorite to coarsely porphyritic leucocratic granite. The stock is silicified and has undergone intense potassic alteration. Coarse twinned plagioclase and potassium feldspar in the original granodiorite have been replaced by fine-grained, untwinned potassium feldspar that has been altered, in part, to sericite and clay minerals.

The north ore body is exposed for about 1,950 ft in a N. 10° E. direction and has a maximum width of about 985 ft. On the north it is covered by talus and glacial debris and on the south by alluvium and Challis Volcanic Group. Host rock for ore is a medium- to dark-green, medium-grained dense pyroxene tactite containing diopside, quartz, feldspar, amphibole, andradite garnet, and epidote adjacent to the stock. Grade of metamorphism within the ore body decreases to the east away from the stock, from tactite to lighter green calc-silicate rock with diopside, wollastonite, tremolite, and quartz. The ore body is a stockwork of quartz, quartz-feldspar, and aplite veins and veinlets that cut the tactite. Most veinlets strike northerly and dip steeply west approximately parallel to bedding. Molybdenite is closely associated with the quartz stockwork, and occurs as rosettes, flakes, fracture fillings, and disseminations in tactite. The frequency of quartz veinlets and grade of molybdenite ore decreases to the east away from the Little Boulder Creek stock. Scheelite is disseminated irregularly in the tactite and in quartz and quartz-feldspar stockwork in the molybdenite ore zone, but molybdenite and scheelite are not found within the same veinlet (Cavanaugh, 1979). The scheelite is present as grains mostly less than 1 mm in diameter, and their distribution within the tactite is erratic but more concentrated along the middle and outer edge of the tactite zone.

The north ore body has been sampled from open cuts and two underground workings by the U.S. Bureau of Mines and subsequently by the American Smelting and Refining Company, who put down a number of drill holes. Kirkemo and others (1965) stated the Bureau of Mines sampling indicated the north ore body contains an appreciable reserve averaging about 0.15 percent MoS_2. Cavanaugh (1979) stated that ore reserves total a minimum of 149 million tons. The U.S. Bureau of Mines collected and analyzed 13 samples from the north zone and 6 from the south zone for WO_3 (Tschanz and others, 1974, p. 1328). They concluded that some scheelite might be recovered, but most of their samples contained less than 0.002 percent WO_3 and the maximum was 0.02 percent WO_3. An analysis of molybdenite from the north ore body contained 77.3 ppm rhenium (Jean Mark Luck, written commun., 1983).

The south ore body crops out in discontinuous small outcrops of tactite about 1,500 ft east of Castle Lake. The north and south ore bodies are separated by 3,100 ft of cover of Challis Volcanic Group and by extensive landslides that flowed north-northwest from a zone of shattered rock along the fault that bounds the high ridge of Challis Volcanic Group on the southeast side of Little Boulder Creek. The area under the volcanics and landslides between the two ore bodies is probably underlain by the ore zone in dark-green pyroxene tactite. Molybdenite is visible in tactite in the south orebody, but the deposit has insufficient outcrops or exploration work to delineate grade and tonnage.

Other areas of Cretaceous stockwork molybdenite are known in the Challis quadrangle and have been prospected to some extent. Two are along the same steep fault that bounds the Little Boulder Creek deposit on the west, but they appear to be small. One is at the northwest end of the easternmost lake of Boulder Chain Lakes and the other is in Big Boulder Basin. A third molybdenite stockwork has been prospected in the Mt. Jordan quadrangle north of Red Mountain at the head of Cabin Creek in the drainage of the West Fork of the Yankee Fork Salmon River. The deposit contains coatings and disseminations of molybdenite in a stockwork in Cretaceous biotite granodiorite that has abundant secondary biotite and muscovite.

Molybdenite has been known at the Virginia-Beth prospect since 1939 (C.P. Ross, written commun., 1943). Molybdenite occurs in a shear zone in granite of the Idaho batholith for a strike length of 700 ft and a width of 50 to 200 ft, but the distribution is erratic and the grade is low.

Descriptive Model

Ore Body

<u>Size</u>: nx10^3 ft long; nx10^2 ft wide; nx10^2 ft thick

<u>Shape</u>: Elongate tabular bodies whose tops are commonly arched or domed.

<u>Tonnage and grade</u>: From 25 to 600 million tons. Grade ranges from 0.055 to 0.16 percent Mo.

Mineralogy

<u>Ore minerals</u>: Molybdenite with or without scheelite, chalcopyrite, galena, and silver minerals

<u>Gangue minerals</u>: Quartz, pyrite, muscovite, and biotite

Major commodities

Listed in decreasing order of importance: molybdenum ± copper ± silver

Character of ore

Quartz stockwork. Molybdenite occurs in fractures, as disseminations, and as selvages in quartz veinlets. Molybdenite commonly associated with coarse muscovite, biotite, and potassium feldspar in pegmatite pods.

Weathering products

Weak to moderate limonite staining and yellow ferrimolybdite after molybdenite. Blue and green copper oxides may also be present. Granitic host rock weathers to grus and limonite-stained clay minerals.

Lithology of host rocks

The deposits are associated with low fluorine I-type compositionally zoned or expanded granitic rocks. Rock types may range from quartz diorite to granite. The molybdenum stockwork may be entirely within the associated granitoid pluton, entirely within the adjacent metamorphosed sedimentary rock, or within both.

Alteration

Central potassic alteration grading outward to phyllic, argillitic, and probably propylitic. Intense silicification associated with ore.

Geochemical indicators

Zoning outward and upward Mo, Ag, ± Cu, ± W, ± Pb, Zn, Ag --> Au

Controlling structures and other features

The shape of the molybdenum stockwork generally is reflected by the external shape of the granitic pluton, particularly by the shape of the crest of the pluton. Stockwork veins may be controlled by joint pattern. Stockwork outside of the pluton is controlled by bedding, joints, faults, and proximity to the intrusive contact.

Geophysical indicators

All the known molybdenum mines and prospects are on the sides of magnetic highs, reflecting the granitic plutons.

Isotope data

Isotope studies indicate that the sulfur had a crustal source and that magmatic hydrothermal fluid was involved in early potassic alteration. Meteoric water mixed with magmatic water during the molybdenite-quartz stage of mineralization.

Resource Assessment

From the descriptive model presented above, four diagnostic and six permissive recognition criteria are defined.

Diagnostic criteria

1. Nearby differentiated or expanded, low-fluorine, I-type granitic plutons or multiple plutons, with high Sr/Rb.
2. Presence of potassic alteration grading outward and (or) upward to phyllic alteration.
3. Local anomalous molybdenum concentrations.
4. Presence of quartz stockwork.

Permissive criteria

1. Argillic alteration and (or) propylitic alteration with disseminated pyrite.
2. Anomalous concentrations of one or more of the following: tungsten, silver, copper, gold, lead.
3. Presence of mineralization in skarn adjacent to granitic plutons.
4. Light limonitic gossan with yellow ferrimolybdite.
5. Margin of magnetic high.
6. Destruction of magnetite in altered granitic plutons.

Using the diagnostic criteria above, the quadrangle was divided into 14 areas (pl. 9) that range from areas with little potential to areas of high potential for Cretaceous stockwork molybdenum deposits. Each area was evaluated for the diagnostic and permissive criteria and the results tabulated in table 25.

Areas 5 and 8 are classified as having high potential. Each has a large stockwork deposit. The Thompson Creek deposit, which was developed and is being mined by the Cyprus Mining Company, has 200 million tons of 0.18 percent MoS_2 with a significant amount of silver. The Little Boulder Creek deposit in area 8 contains a measured resource of >100 million tons of ore containing 0.15 percent MoS_2 and 0.02 percent tungsten in scheelite. Area 8 has molybdenite mineralization in skarn in at least three other localities on the east side of the White Cloud stock.

Areas 2, 9, 11, 12, and 14 are classified as having moderate potential for Cretaceous molybdenum stockwork deposits. Areas 9, 11, 12, and 14 have some stream-sediment samples with anomalous molybdenum concentrations and contain granitic rocks that range in composition from granodiorite to leucogranite. Known molybdenite occurrences, however, appear to be subeconomic. These include the molybdenite stockwork mineralization at the head of Cabin Creek in the Mt. Jordan quadrangle and mineralization at the Virginia-Beth prospect. Anomalous molybdenum concentrations were found on the

Table 25. Recognition criteria for Cretaceous molybdenum stockworks (see pl. 9)

Map area	Diagnostic: Expanded low-F granitic pluton with high Sr/Rb	Diagnostic: Potassic-phyllic alteration	Diagnostic: Anomalous molybdenum	Diagnostic: Quartz stockwork	Diagnostic: Total	Permissive: Argillic and (or) propyllic alteration	Permissive: Anomalous concentrations W, Ag, Cu, Au, Pb	Permissive: Presence mineralized skarn	Permissive: Gossan with yellow ferrimolybdite	Permissive: Margin of magnetic high	Permissive: Destruction of magnetite in altered granite	Total	Resource potential
1	-1	-1	1/2	0	-1 1/2	-1	-1	0	0	-1	0	-3	Low
2	1	0	1/2	0	1 1/2	1/2	1	0	0	1	0	2 1/2	Moderate
3	0	-1	0	0	-1	0	1/2	0	0	1	0	1 1/2	Low
4	0	-1	-1	0	-2	0	1/2	0	0	1	0	1 1/2	Low
5	1	1	1	1	4	1	1	1	1	1	1	6	High
6	0	0	1/2	0	1/2	1/2	1/2	1/2	1/2	1/2	0	2 1/2	Low
7	1	0	-1	0	0	0	0	0	0	-1	0	-1	Low
8	1	1	1	1	4	1	1	1	1	1	1	6	High
9	1	0	1	0	2	1/2	1	1	1	0	0	3 1/2	Moderate
10	-1	-1	0	-1	-3	-1	-1	0	-1	-1	0	-4	Low
11	1	0	1	1/2	2 1/2	1/2	1/2	0	1/2	1/2	0	2	Moderate
12	1	0	1	0	2	0	0	0	-1	-1	0	-2	Moderate
13	1/2	0	-1	0	- 1/2	-1	0	-1	-1	0	0	-3	Low
14	1	0	0	0	1	0	1/2	1/2	0	1/2	0	1 1/2	Moderate

west side of area 12, in an area underlain by Cretaceous biotite granodiorite and leucogranite. No molybdenite prospects are known in the area.

Map areas 1, 3, 4, 6, 7, 10, and 13 are considered to have low potential for Cretaceous molybdenum stockwork deposits. They are distant from granitic plutons (areas 1 and 10) or are in granitic terrane but have no anomalous molybdenum concentrations in stream-sediment samples.

Fluorine-deficient molybdenum deposits in the Soviet Union have been shown to grade upward or outward to disseminated gold deposits (Tunyan, 1971). Although zones of gold enrichment have not been recognized with the Idaho deposits, their paragenesis is similar to that of the Soviet deposits. This suggests that some potential for gold exists wherever there is potential for fluorine-deficient molybdenum deposits such as we find in the Challis quadrangle.

TERTIARY MOLYBDENUM STOCKWORKS

By Thor H. Kiilsgaard and Earl H. Bennett

The largest and potentially most promising Tertiary molybdenum deposits in the Challis quadrangle are vein stockworks and disseminated occurrences. These deposits have features in common. They are in or near hypabyssal rocks of Eocene age. The host rocks are intensely altered; the core of the altered area is usually mineralized and silicified. Pyrite is the dominant sulfide gangue mineral within and surrounding the core area, which in turn is surrounded by broad zones of argillized and sericitized rock. The deposits tend to be elongate, the long dimension being along the zone of major fracturing and intrusion. The deposit may consist of a number of subparallel quartz veins that range from a few inches to a few feet in thickness, between which are a myriad of connecting quartz veinlets and stringers, all of which comprise a vein-stockwork system. Molybdenite may occur as rosettes and aggregations along the quartz veinlets, as hair-thin veinlets of molybdenite, and as disseminated flecks in the wall rock. The deposits contain minor amounts of copper and silver minerals. Some also contain minor quantities of gold. Typical of these deposits is the CUMO and Little Falls deposits in the southwest corner of the quadrangle, and the Red Mountain deposit north of Yellow Pine. A mineralized area at the headwaters of Big and Little Silver Creek along the southern border of the quadrangle may be a deposit of this type.

The CUMO deposit is on the south side of Grimes Creek, at the common corner of sections 7, 8, 17, and 18, T. 8 N., R. 6 E. The deposit was discovered by AMAX Exploration in 1963 and was explored by Curwood Mining Co., Midwest Oil Co., and AMAX-AMOCO from 1968 to 1984 (Baker, 1985). Exploration included extensive bulldozer cuts and more than 25 diamond drill holes that were drilled in a northeast-trending area of about 2 square miles.

The deposit consists of a stockwork of quartz veinlets that contain pyrite, chalcopyrite, and molybdenite. The veinlets generally are less than 2 mm thick; they cut Cretaceous biotite granodiorite of the Idaho batholith and a swarm of northeast-trending Eocene dikes, most of which are of rhyolitic composition. The veinlets are more or less concentrated in narrow rhyolite dikes, although at least one rhyolite dike and several small diabase dikes are post-mineral in age. The core of the deposit is an intensely silicified zone, almost completely encircled by a pyritic envelope that is 600 to 700 ft wide on the eastern side of the deposit (Whitney, 1975).

The host rocks are intensely altered. Propylitic and argillic alteration is overprinted by potassic alteration and silicification. Sericite is ubiquitous in the altered rocks (Whitney, 1975). Erosion and oxidation of the deposit give the outcrop area a strong copper and molybdenum geochemical anomaly (Shannon, 1971).

Baker (oral commun., 1985) estimated the CUMO deposit to contain one billion tons of material with an average grade of 0.10 percent MoS_2. This grade is too low to be minable in 1985, and the depth to better grade material in the deposit would make it difficult to mine by open-pit methods; nevertheless, the deposit must be considered as a significant molybdenum resource.

The Little Falls molybdenite deposit is along the South Fork of the Payette River at the junction of the river with Big Pine Creek, about 11 mi east of Garden Valley. The deposit is similar to CUMO in that it is a stockwork of quartz veinlets that contain molybdenite. The veinlets cut a swarm of northeast-trending Eocene dikes, most of which are of rhyolitic composition. Some dikes at the deposit are post-mineral in age. Fission-track dating of zircon from a pre-mineral rhyolite dike at the deposit gave an age of 29.3±1.7 m.y. (Paul Andriessen, written commun., 1982). The swarm of rhyolitic dikes may be traced southwest to the vicinity of the CUMO deposit.

Rostad (1967) described the Little Falls deposit as being in an extensive pyritized zone, of which the most intensively pyritized section is about 10,000 ft long and 2,000 ft wide and within which molybdenite is exposed over an area 1,000 ft wide and 3,000 ft long. Oxidation of the more pyritized rocks has colored the outcrop a reddish-brown and has created a strong molybdenum geochemical anomaly over part of the deposit (Rostad, 1967). Argillic and sericitic alteration of feldspars in the country rock is widespread at the deposit. The central part of the deposit, where pyrite and molybdenite are most abundant, is silicified by a concentration of quartz veinlets (Donovan, 1962) and by siliceous replacement of the host rock.

The Little Falls deposit was discovered in 1960 by Congden and Carey, a Denver, Colo., firm. Between 1963 and 1980 three different owners drilled over 50 holes in the area, totalling more than 33,000 ft. The most recent owner, Abella Resources, also drove an adit 784 ft north from a portal on the north side of State Highway 17, 1,600 ft west of the bridge across Big Pine Creek. Abella's assay data resulted in a weighted average grade of 0.05 percent MoS_2. These extensive exploration programs have shown that Little Falls is a multi-million ton deposit which is too low in grade to be mined under present (1985) economic conditions.

The Red Mountain deposit is in sec. 3, T. 19 N., R. 8 E., about 3 mi north of Yellow Pine. Only the southern end of the deposit is in the Challis quadrangle. The deposit is a stockwork of quartz veins and veinlets about 2,700 ft long and 2,000 ft wide. It contains a large cap of barren quartz about 1,350 ft long and 350 ft wide (Erdman and others, 1985). The stockwork contains molybdenite, scheelite, and stibnite. Other sulfide minerals include sparse pyrrhotite, ubiquitous pyrite, and arsenopyrite. The deposit is enveloped by a large argillic alteration zone. Although exploration to date has not disclosed significant amounts of molybdenite and soil samples are low in molybdenum, biogeochemical anomalies in gold and molybdenum have been found at the surface. Of particular interest is gold in samples taken from douglas-fir (<u>Pseudotsuga menziesii</u>) and molybdenum contained in the leaves of beargrass (<u>Xerophyllum tenax</u>) (Erdman and others, 1985). The locality is considered a good target for a concealed molybdenum deposit.

Sediment samples from streams tributary to Big and Little Silver Creeks, east of the headwaters of Bear River and along the south border of the Challis quadrangle, are anomalous in molybdenum and silver (Kiilsgaard, 1982; 1983a, b). The southern part of the anomalous area, immediately south of the quadrangle border, is underlain by highly kaolinized Cretaceous biotite granodiorite that is in fault contact with Eocene pink granite. A large body of quartz more than 40 ft thick and 3,000 ft long cuts the altered biotite granodiorite and an Eocene dike. Another quartz vein trends along the footwall of an Eocene andesite dike and contains fragments of the dike, and therefore is younger. Other quartz veins in the altered rocks carry appreciable quantities of gold and silver (Kiilsgaard and others, 1983). Another mineralized area about 5 mi to the northwest, south of the sharp bend in Crooked River, also is anomalous in molybdenum and silver. Both areas have a moderate potential for a significant molybdenite ore body, but neither has been explored adequately.

Molybdenite is also a common mineral in many veins of the Challis quadrangle, but usually in such scanty amounts that it is of interest only from a mineralogical standpoint. Local concentrations of molybdenite in veins, as at the Virginia-Beth prospect (pl. 10), may assay one percent or more MoS_2 (C.P. Ross, written commun., 1943), but the known amount of molybdenite in such occurrences is small. Molybdenite also is widely disseminated in Tertiary granite (Kiilsgaard and others, 1970), although minable concentrations of molybdenite have not been found in such rock. Anomalous amounts of molybdenum also occur in high-level Tertiary rhyolite, which is compositionally similar to the Tertiary granite. Johnson and Fisher (this volume, p. 163) have called attention to the possibility of molybdenum deposits beneath high-level rhyolite.

Descriptive Model

Ore Body

Size: $nx10^3$ ft long; $>10^3$ ft wide.

Shape: Somewhat oval shaped in plan view, the long axis more or less parallel to the trend of the Eocene dike host rocks and the more pronounced pre-mineral shear zones that have guided emplacement of the dikes and ore bodies.

Tonnage and grade: Tens to hundreds of millions of tons of mineralized material, the grade of which is low, generally less than 0.15 percent MoS_2. Copper and silver may be present in minor amounts. May contain trace amounts of gold.

Mineralogy

Molybdenite and chalcopyrite are the principal ore minerals and quartz and pyrite the principal gangue minerals.

Commodities

The major commodity is molybdenum with minor amounts of copper.

Character of ore

Stockwork of veins and veinlets that contain molybdenite and chalcopyrite, some of which also is disseminated in the host rock.

Lithology of host rocks

Eocene hypabyssal dikes and stocks, some of which intrude older granodiorite.

Weathering products

Oxidation of pyrite in the mineralized deposit gives the outcrop a reddish-brown color, which serves as a distinctive color anomaly.

Alteration

Host rocks of the deposits are intensively altered. A siliceous core surrounded by envelopes of argillized, sericitized, and chloritized rocks is common.

Geochemical indicators

Sediments of streams draining the deposits and soil in the outcrop areas are anomalous in molybdenum and copper, and some stream sediments are anomalous in silver.

Ore controls

The rhyolitic dikes are the primary structural controls, along with the dominant pre-mineral faults that commonly have guided emplacement of the dikes and the ore bodies.

Resource Assessment

From the above descriptive model, we define ten recognition criteria of which three are diagnostic and seven are permissive.

Diagnostic criteria

1. Presence of Tertiary quartz stockworks.
2. Presence of Eocene dikes and stocks intrusive into Cretaceous granitic rocks.
3. Presence of extensive hydrothermal alteration.

Permissive criteria

1. Trace to moderate amounts of molybdenite throughout a broad elongate zone.
2. Trace amounts of associated silver and copper.
3. Anomalous molybdenum in stream sediments or in panned concentrates.
4. Anomalous molybdenum in soil samples.
5. Location within the trans-Challis fault system.
6. Presence of a siliceous core surrounded by a pyritic envelope.

On the basis of the criteria, twelve areas in the quadrangle were identified as potential localities for Tertiary molybdenum deposits (pl. 10), and each area was scored numerically as shown in table 26. From these scores we interpret the resource potential of the areas as follows:

High potential: areas 1, 11, and 12

Moderate potential: areas 2, 6, and 10

Low potential: areas 3, 4, 5, 7, 8, and 9.

In the areas of high potential, we believe it probable that at least one deposit similar in character and size to the model described remains to be discovered. Of particular interest is area 12, which contains both the CUMO and Little Falls prospects. Although low in grade, these prospects contain enormous tonnages of mineralized material. Both properties are parts of the same dike swarm; thus parts of the area between the two are attractive prospecting targets. Area 10 has a moderate potential and no doubt would have been explored had it not been withdrawn, first as a Forest Service Primitive Area and more recently as a Wilderness. Area 6 contains the Cretaceous Thompson Creek molybdenum deposit (Hall, this volume, p. 152). It also contains a stock of high-level rhyolite, the lower parts of which could be an exploratory target for a Tertiary molybdenum deposit. The remainder of the quadrangle, that is the areas not considered above, has a low potential for additional Tertiary molybdenum stockworks, due to absence of diagnostic criteria. More detailed work in these areas could bring to light evidence of the sort we have used to delineate potential, but no such information is known to us at this time.

Table 26. Recognition criteria for Tertiary molybdenum stockworks (see pl. 10)

Map area	Diagnostic: Presence of Tertiary quartz stock-works	Diagnostic: Presence of MoS_2 in stockworks or dissemi-nations	Diagnostic: Eocene rhyo-lite dikes and stocks intrusive into Creta-ceous granodiorite	Diagnostic: Extensive hydrothermal alteration	Total	Permissive: Molybdenite occurs throughout a broad elongate zone	Permissive: Trace amounts of associated silver and copper	Permissive: Anomalous molybdenum in stream sediments or panned concentrates	Permissive: Anomalous molybdenum in soil samples	Permissive: Area is within the trans-Challis fault system	Permissive: Presence of siliceous ore with pyritic envelope	Total	Resource potential
1	1	1	1	1	4	1	0	1	1	-1	1	3	High
2	1/2	1/2	1/2	0	1 1/2	1	1	1	0	-1	0	2	Moderate
3	0	0	0	0	0	0	1	1	0	1	0	3	Low
4	0	0	-1	1	0	0	0	0	0	1	0	1	Low
5	0	0	-1	1	0	0	0	0	0	1	0	1	Low
6	0	1/2	1	1	2 1/2	1	1	0	0	1	1	4	Moderate
7	0	0	-1	1	0	0	1	1	0	1	0	3	Low
8	0	0	0	1	1	0	-1	1	0	1	0	1	Low
9	0	1/2	1	0	1 1/2	0	1	1	0	0	0	2	Low
10	0	1/2	0	1	1 1/2	1	1	1	0	-1	0	2	Moderate
11	1/2	1/2	1	1	3	1	1	1	0	0	1	4	High
12	1	1	1	1	4	1	1	1	1	1	1	6	High
13	(see text)												Low

HIGH-LEVEL RHYOLITE-HOSTED PRECIOUS-METAL DEPOSITS

By Kathleen M. Johnson and Frederick S. Fisher

Precious-metal deposits in hydrothermally altered high-level rhyolites are found primarily in the north-central part of the Challis quadrangle. The term "high-level" implies uncertainty as to how close these intrusives came to the surface--some breached it, others did not. The cooling history, hydrothermal fluid flow, and mineralization of rhyolites that vented is probably different from those that did not.

The rhyolites are mostly domes and dikes that formed within or near the trans-Challis fault system. Their surface expression ranges from poorly exposed dikes and irregular small intrusive bodies to well-preserved exogenous domes, such as on the summit of Mt. Greylock. Not all high-level rhyolites are mineralized and altered; those that are contain bleached, iron-stained, and commonly silicified rock. Where fresh, these rocks are mostly porphyritic to aphyric alkali rhyolites. They crosscut the youngest flows and lavas in the volcanic sequence. Zircons from the youngest intrusive rock in the Red Mountain rhyolite yielded an age of 39.1±2.0 m.y. (P. Andriessen, written commun., 1982) and zircons from an aggregate of mineralized rhyolite and tuff from the Sunbeam mine yielded an age of 45.8±2.3 m.y. (Johnson and McIntyre, 1983).

Known deposits of this type include the Sunbeam mine (Anderson, 1949), Parker Mountain (Ross, 1927, 1934b), Rabbit Foot (Ross, 1927), and Singheiser deposits (Ross, 1927). Production from these deposits has been relatively small (see table 27), and most of the recorded production has come from the larger, higher grade quartz veins that are commonly associated with these high-level rhyolites. Despite their meager production, we believe that additional precious-metal resources are present as low-grade ores in the network of small (less than 1/4 in.) quartz stockwork veins and as disseminations in the altered host rhyolites. In 1980-1984 there were no active mines in deposits of this type, but there was extensive exploration activity, and a pilot production project had been completed at the Golden Sunbeam mine.

Descriptive Model

Ore Body

Size: $n \times 10$-$n \times 10^2$ ft wide; $n \times 10^2$-$n \times 10^3$ ft long; $n \times 10$-$n \times 10^2$ ft thick

Shape: Elongate to ovoid in plan; narrowing with depth to linear fault zones.

Tonnage and grade: $n \times 10^6$ tons of ore varying from 0.02 to 1.0 oz gold; gold/silver ratios highly variable; ratios at Parker Mountain range from 1:3 to 1:6 (Ross, 1934b).

Mineralogy

Ore minerals: Electrum>>native gold>>native silver

Gangue: Secondary silica > clay minerals (illite > kaolinite > ?) > pyrite

Minor but significant: Zircon, apatite, fluorite, amethystine quartz

Commodities

Gold and silver.

Character of ore

Ore minerals concentrated in irregular quartz veins and stockworks, in vugs, in open space in breccias, and as disseminations in host rock. Major past production has been from quartz veins as much as 3 ft thick.

Table 27. Historic production from high-level rhyolite-hosted precious-metal deposits. This production is largely from high grade veins

[Data from U.S. Bureau of Mines, Spokane, Wash.]

	Gold (oz)	Silver (oz)
Golden Sunbeam (including Bismark)	18,160	23,778
Parker Mountain (Williams and Parker)	819	4,520
Rabbit Foot	116	136
Singheiser	317	8,415

Lithology of host rock

1. Massive to flow-laminated rhyolites, for the most part porphyritic to aphyric, and generally containing less than 10 percent phenocrysts. Sanidine and quartz are the most abundant phenocryst minerals.
2. Chemically they are alkali rhyolites, with an average of 76 percent SiO_2, 5.1 percent K_2O, 3.6 percent Na_2O, and 0.3 percent CaO (Hardyman and Fisher, 1985).
3. Autobrecciated rhyolites are common and pebble dikes may be present (McIntyre and Johnson, 1983).

Alteration

Altered rhyolites are commonly bleached, iron stained, and silicified. Hydrothermally altered zones contain clay pseudomorphs after feldspar and variable amounts of secondary and remobilized silica.

Geochemical and mineral indicators

Geochemical: Stream sediments are commonly enriched in Ag, As, Au, Be, Mo, Se, and Zr (McDanal and others, 1984).

Mineral: Zircon, pyrite, amethystine quartz, fluorspar, clays.

Controlling structures and other features

1. Rhyolites occur on or near bounding fault zones of volcanotectonic features, mostly within the trans-Challis fault system.
2. Ores within rhyolites are controlled by fracture systems which reflect the major structural trends. The fracture systems are commonly zones of shattering on which little or no motion has occurred.
3. At Golden Sunbeam deposit, highest gold values in drill core are found within 20 ft of the boundary between oxidized and unoxidized rock.
4. Ores are not necessarily confined to rhyolite. Vein and disseminated ores occur in structures that crosscut both the rhyolite and the surrounding country rock.

Resource Assessment

From the descriptive model above, we define nine recognition criteria, of which we consider five diagnostic and four permissive.

Diagnostic criteria

1. Evidence of precious-metal mineralization. This may be either geochemical anomalies, mines or prospects, or placer deposits.
2. Presence of high-level rhyolites.
3. Proximity to bounding faults of major volcanotectonic features.
4. Deposits are within the central and north-central parts of the trans-Challis fault system. Favorability increases with proximity to the northwest boundary of the Custer graben and its extension northeast into the bounding faults of the Panther Creek graben.
5. Presence of anomalous concentrations of secondary and remobilized silica in stockworks or veins or flooding the original rock.

Permissive criteria

1. Presence of anomalous amounts of any or all of the following elements: As, Be, Mo, Se, or Zr.
2. Presence of anomalous concentrations of any or all of the following minerals: zircon, pyrite, amethystine quartz, fluorite, or clays.
3. Extensive fracturing and brecciation of host rocks.
4. Presence of argillic alteration.

Using the diagnostic and permissive recognition criteria, we divided the quadrangle into 16 areas (pl. 11). We then scored these areas and ranked them as to their resource potential (table 28). Two areas (6 and 8) were ranked as having high potential, four areas (2, 5, 7, and 10) as having moderate potential, and the remaining areas as having low potential for precious-metal deposits in high-level rhyolites.

The meaning of these evaluations can be better expressed qualitatively than quantitatively or statistically. Qualitatively, we believe the available data indicate that areas 6 and 8 should have top priority as target areas in prospecting for precious-metal deposits in high-level rhyolites. That is to say, we believe the combination of recognition criteria is so compelling as to indicate a very high probability that at least one additional ore deposit comparable to the descriptive model occurs in each of areas 6 and 8. Similarly, we believe the combinations of recognition criteria in areas 2, 5, 7, and 10 are sufficiently compelling as to indicate a lower but still significant probability that one additional ore deposit comparable to the descriptive model occurs in each area. In our opinion, the probability of finding a deposit of this type in areas ranked as having low potential is quite small.

It is interesting to speculate about the "roots" of the high-level rhyolites. Mapping shows that these rhyolites occur within the trans-Challis fault system, suggesting the likelihood of linear feeder systems. All of these high-level rhyolites contain anomalous molybdenum. By analogy with the Little Falls molybdenum deposit (Kiilsgaard and Bennett, this volume, p. 158) in the Boise Basin dike swarm at the southern end of the trans-Challis fault system, we suggest that a Little Falls-type molybdenum deposit may exist at depth beneath the high-level rhyolites. The molybdenum resource potential in the high-level rhyolites is unknown.

GRAPHITE IN METAMORPHIC ROCKS

By Thor H. Kiilsgaard

Graphite is common in the carbonate and schist facies of certain metamorphosed sedimentary rocks of the Challis quadrangle. It is conspicuous in metamorphic rocks exposed at Thompson Peak (pl. 1) about 7 mi southwest of Stanley (Reid, 1963), and along Fishhook Creek (44°08′ N., 114°59′ W.) southeast of Thompson Peak. Graphitic schist is exposed along the eastern side of Elk Mountain (pl. 1) about 7 mi northwest of Stanley, and southeast of Elk Mountain, near the junction of Stanley Lake Creek and Stanley Creek with Valley Creek (44°15′ N., 115°00′ W.) (Fisher and others, 1983). Roof pendants of metamorphosed graphitic carbonate rocks cap the ridge northwest of Bull Trout Point (44°20′ N., 115°17′ W.), are exposed in the road bank about 1 1/2 miles east of the Elk Creek Ranger Station (44°25′ N., 115°24′ W.), and crop out on the high ridge extending southeast from the Deadwood mine (pl. 1).

The age of the graphite-bearing metamorphosed rock is uncertain. On the Challis quadrangle geologic map (Fisher and others, in press), the rocks are shown as Paleozoic(?) or Precambrian(?). The graphite content of the rocks indicates that they more likely are of Paleozoic age. Relatively unmetamorphosed sedimentary rocks of Paleozoic age in the southeast part of the quadrangle contain sufficient carbonaceous material to account for the graphite in the metamorphic rocks, whereas known Precambrian sedimentary rocks in the quadrangle do not.

Table 28. Recognition criteria for high-level rhyolite-hosted precious metal deposits (see pl. 11)

Map area	Diagnostic criteria: Evidence of precious metals	High level rhyolites	Major bounding faults	North part of trans-Challis fault system	Anomalous silica	Total	Permissive criteria: Anomalous As, Be, Mo Se, or Zr	Anomalous minerals	Fracturing and brecciation	Argillic alteration	Total	Resource potential
1	1	0	0	0	0	1	1/2	1/2	1/2	1/2	2	Low
2	1	1/2	1	-1	1	2 1/2	1	1	1	1	4	Moderate
3	1/2	0	0	0	1/2	1	1/2	1/2	1/2	0	1 1/2	Low
4	1	0	1/2	-1	1/2	1	0	1/2	1	1/2	2	Low
5	1/2	1/2	1	1/2	1	3 1/2	1/2	1/2	1/2	1/2	2	Moderate
6	1/2	1	1	1	1	4 1/2	1	1	1	1	4	High
7	1/2	1/2	1/2	1/2	1	3	1/2	1/2	1/2	1/2	2	Moderate
8	1	1	1	1/2	1	4 1/2	1	1	1	1	4	High
9	0	1	-1	-1	0	-1	0	0	0	0	0	Low
10	1	1	1	1	0	4	0	1/2	0	0	1/2	Moderate
11	0	1	1/2	1/2	0	2	0	0	0	0	0	Low
12	0	1	1/2	1/2	0	2	0	0	0	0	0	Low
13	0	1	1/2	1/2	0	2	0	0	0	0	0	Low
14	0	1	1	-1	1	2	0	1/2	1/2	0	1	Low
15	0	1	-1	-1	0	-1	0	0	0	0	0	Low
16	0	1	1/2	-1	0	1/2	0	0	0	0	0	Low

At the Gem State mine (pl. 1), at the northwest end of Elk Mountain, crystalline flake graphite in graphitic schist ranges in size from minus 35 to plus 200 mesh (less than 0.42 mm to more than 0.07 mm). Five samples of the graphitic schist taken by the Bureau of Mines (Tschanz and others, 1974) ranged from 1.07 percent to 3.00 percent organic carbon and averaged 1.54 percent, a low graphitic content for a minable deposit. If the graphitic schist extends from the northwest end to the southeast end of Elk Mountain, as is very likely, the potential resources of graphitic material at that locality would be in the order of millions of tons (Tschanz and others, 1974, p. 524).

The ready availability of foreign graphite, limited industrial demand, low grade of graphite in graphitic rocks of the Challis quadrangle, and the great distance to market are factors that argue against the Challis quadrangle graphite ever being mined. At best the graphitic material can be considered a subeconomic resource.

MICA, FELDSPAR, COLUMBITE, AND RARE-MINERAL PEGMATITES

By Thor H. Kiilsgaard

Pegmatites are coarse-grained, irregular-textured masses of igneous rock found within and around the borders of batholiths of plutonic rock. The chief minerals are feldspars, quartz, and mica. Beryl, columbite-tantalite, cassiterite, scheelite, spodumene, tourmaline, various uranium minerals, and other rare minerals also are found in pegmatites. Many pegmatites are zoned, more or less concentrically, each zone being characterized by distinctive mineral assemblages and grain sizes. The core zone usually is quartz. Pegmatites have been intruded into the rocks that enclose them, and their shapes are determined by preexisting structures in the host rock. The most common form is dikes that may range from a few inches to thousands of feet in length and from a fraction of an inch to hundreds of feet in width. Some pegmatites are pipe-like structures, whereas others are tabular or irregular-shaped bodies. Countless pegmatite dikes intrude the Cretaceous Idaho batholith, as well as the Eocene plutonic rocks. Most of them are only a few inches thick and a few feet long and do not contain economic minerals in minable quantity.

Several pegmatites, three of which have been prospected, are in the southwest corner of the Challis quadrangle, southwest of Garden Valley, in the vicinity of Wash and Horn Creeks (44°02′ N., 115°55′ W.) (Fisher and others, in press). The pegmatites cut biotite granodiorite of the Idaho batholith. The Columbite pegmatite, in sec. 19, T. 8 N., R. 5 E., is an oval-shaped mass about 250 ft long and at least 200 ft wide. It has been explored by several bulldozer cuts and a 160-ft tunnel. Fryklund (1951) described the pegmatite as having a graphic granite wall zone, a plagioclase-quartz-mica intermediate zone, an inner microcline zone, and a quartz core. Scrap mica, sheets of which are as much as 1 1/4 in. in diameter, is concentrated in the plagioclase-quartz zone. Also present in the zone are columbite, samarskite, and monazite. He described a 309-lb crystal with an inner zone of columbite and an outer zone of samarskite that was found at the west portal of the tunnel in 1950. A 100-lb samarskite crystal was found nearby. Fryklund (1951) also noted that about 85 ft of the western part of the tunnel cuts almost pure microcline. Stoll (1950) called attention to a zone 2 to 3 ft thick that contained books of muscovite as much as 16 in. in diameter. The muscovite is pale yellow, but most of it is marred by a crisscross pattern of black stain and by "A" structure. Samples of the mica were submitted to the

Colonial Mica Corp. during World War II for analysis but were found to be unsuitable for strategic use (L.E. Shaffer, written commun., 1944). H.M. Bannerman (written commun., 1950) considered the microcline to be suitable for use in the ceramic or glass industries, but believed the material to be too far from a market to be of commercial value.

According to Stoll (1950) the Columbite prospect has been worked intermittently for columbite and mica since about 1900, and about 500 lbs of columbite was reported to have been produced, most of which apparently was in a few crystals. No columbite crystals were found by Stoll (1950) and 15 samples taken in 1950 by Popoff (U.S. Bureau of Mines, unpublished report) contained negligible amounts of niobium or tantalum or none at all. There is no record of mica or feldspar having been produced from the mine.

Other pegmatites in the vicinity of the Columbite prospect include the Mica Dome property in sec. 18, T. 8 N., R. 5 E., the Bowman and Mirandeborde prospects in sec. 12, T. 8 N., R. 4 E., and other poorly exposed pegmatites on the ridge west of Wash Creek (Fryklund, 1951). Most of these have been prospected to some extent, but none have produced any feldspar, mica, or other minerals.

The Mica Slim pegmatite in sec. 22, T. 9 N., R. 5 E., about 7 mi northeast of the Columbite prospect, is one of several small pegmatites in the area that are in biotite granodiorite. Stoll (1950) described the pegmatite as 8 to 12 in. wide and exposed over a length of 15 ft. Mica books in the pegmatite are small and reeved, and niobium, tantalum, and beryllium were not detected in samples of the pegmatite taken by L. E. Shaffer (U.S. Bureau of Mines, unpublished report, 1944).

The Panther pegmatite prospect is 1 3/4 mi northeast of Boiling Springs in sec. 14, T. 12 N., R. 5 E. The pegmatite is in biotite-muscovite granite of the Idaho batholith and is exposed for about 200 yds along a steep hillside (Stoll, 1950). The principal minerals in the pegmatite are microcline, quartz, and plagioclase. Radial books of muscovite occur in the feldspars, but the muscovite is reeved and stained. There is no evidence that any minerals have been mined from the prospect.

Exposures of blue-green beryl (aquamarine) are known in the Sawtooth Range (Reid, 1963; Pattee and others, 1968; Kiilsgaard and others, 1970). The aquamarine occurs as erratic disseminations, often as single crystals, as radial aggregates, as euhedral crystals in vugs, and as concentrations in pods and along fractures in pink Eocene granite of the Sawtooth batholith. Concentrations of aquamarine also occur in pegmatite dikes that intrude the Eocene granite. Most of the aquamarine is translucent, contains inclusions, is cracked or contains other imperfections, and is not of gem quality. Some transparent gem-quality aquamarine crystals have been found in vugs and as float. Most of the known Sawtooth pegmatites that contain aquamarine are south of the Challis quadrangle. A pegmatite dike at the Stanley Ace prospect, north of Stanley Lake, contains beryllium-bearing idocrase (vesuvianite), but samples of the pegmatite contained only trace amounts of beryllium (0.001-0.003 percent BeO) (Pattee and others, 1968). No exposures were seen in the Challis quadrangle that contained sufficient beryl to be considered as an economic source of beryllium.

Kelly and others (1956) described the Kingsley deposit, which is about 3 mi east of Grimes Pass in Boise County, as a 50-ft pegmatite in which white quartz and feldspar are the principal minerals. They also mentioned a pegmatite reported to contain high-quality feldspar in T. 16 N., R. 3 or 4 E., south of Gold Fork, a tributary of the North Fork Payette River.

There is no evidence of recent prospecting or mining activity at any pegmatite in the Challis quadrangle. The pegmatites could be considered as resources, as many of them contain minerals that are used by industry. However, the distance and cost of transportation to market, rugged terrain and inaccessibility of the area during the long winter season, small size of most of the pegmatites, inferior quality of the muscovite, and the sparse content of rare minerals of economic interest are factors that make profitable mining of the deposits unlikely.

PIEZOELECTRIC QUARTZ CRYSTAL-BEARING PEGMATITES

By Thor H. Kiilsgaard

Quartz is mined for a variety of industrial purposes, three of which are the preparation of silicon, for use as a smelter flux, and for piezoelectric usage. Silicon (Si) is derived from high-purity quartz, usually 99 percent or more SiO_2, but there is no record of quartz having been mined in Idaho for that purpose. Siliceous gold ores generally are in demand at smelters that require acid fluxes. There may be mines in the Challis quadrangle from which gold-silver ores have been shipped for use, in part, as a smelter flux, but there is no record of siliceous ore having been shipped solely for use as a smelter flux. Mining and transportation costs would make such usage prohibitively expensive.

Crystalline material that lacks a center of symmetry is piezoelectric, and quartz is among the more effective known piezoelectric substances. Piezoelectric-grade quartz crystals that are free of all defects are used for accurate electronic frequency control, filtration in electronic circuitry, and as optical quartz. Natural quartz crystals formerly were used and the crystals were imported, chiefly from Brazil. Since the late 1950's, most quartz crystals used for piezoelectric purposes have been grown synthetically.

In the late 1940's efforts were made to produce piezoelectric quartz crystals from a deposit along the west border of the Challis quadrangle. Principal working pits of the deposit, known formerly as the Goodenough prospect ($44^\circ48'$ N., $116^\circ00'$ W.) and later as the Jacobs quartz property, are in section 19, T. 17 N., R. 4 E., about 2,000 ft west of the border of the quadrangle. Large quartz crytals are reported to have been produced, one of which is said to have weighed 63 lbs. A clear quartz crystal from the deposit, examined by Mr. Hugh Waesche, U.S. Signal Corps laboratories, was 10 in. in diameter and 14 in. long (personal commun., 1951). Another quartz crystal from the deposit was tested in the U.S. Signal Corps laboratory and found to be badly fractured, twinned, and unusable for piezoelectric purposes. Two hundred tons of quartz was mined from the deposit in 1949 and used as brick facing, but there is no record of any of the quartz ever having been used as piezoelectric quartz.

The Erwin Mickey quartz property ($44^\circ41'$ N., $115^\circ43'$ W.) is near the mouth of Six-bit Creek, about 3 mi northwest of Warm Lake (Mitchell and others, 1981). A sample from the deposit contained 97.3 percent SiO_2 (U.S. Bureau of Mines, unpublished report), but nothing is known about the size or physical properties of the deposit.

The Columbite prospect (pl. 1) pegmatite, about 5 mi southeast of Garden Valley, in sec. 19, T. 8 N., R. 4 E., has a quartz core that is 175 ft long and 50 ft wide, but there is no available information on the grade or physical character of the deposit. There is no record of quartz having been shipped from the deposit.

There are no known piezoelectric-quality quartz deposits in the Challis quadrangle. There may be quartz deposits of sufficient quantity and quality to be considered as a resource for high-purity silicon, but the distance from market and transportation costs make the mining of such deposits for silicon unlikely.

SEMIPRECIOUS GEMSTONES IN MIAROLITIC CAVITIES

By Earl H. Bennett

Crystals of smoky quartz, microcline, topaz, and beryl (aquamarine) have been collected from the pink granites of Tertiary age in Idaho for many years. Associated accessory minerals include fluorite, carpholite, bertrandite, helvite, and ilmenite.

All of the Tertiary pink granites in Idaho contain miarolitic cavities with euhedral minerals, and several produce fine crystals. Most notable is the Sawtooth batholith, but crystals have also been collected from the Bungalow pluton, the Twin Springs pluton, the Crags pluton, and the Lolo batholith, all outside the Challis quadrangle.

The miarolitic cavities in the granites are often aligned along healed fractures and joints, and some collectors believe that in the Sawtooth batholith they are also confined to a certain horizon. They are able to predict the elevation and location of the cavities by looking at fault movements indicated on geologic maps.

The most common semiprecious gemstone in the Tertiary granites is smoky quartz. Individual crystals reach a length of 16 in. and weigh up to 100 lbs. The crystals occur singly, in groups, and occasionally with microcline, topaz, and fluorite reminiscent of the Pike´s Peak, Colorado, specimens except that the Idaho microcline is typically tan or white compared to the blue-green amazonite from Pike´s Peak. The quartz gets its smoky color from defects in the crystal lattice caused by radioactivity. The Tertiary granites are high in background uranium and thorium, and radiation from these sources probably caused the smoky color. Many of the crystals turn clear when exposed to sunlight on talus slopes, and smoky quartz will turn clear when heated in the laboratory (Nassau, 1978). Some of the smoky quartz crystals are gem quality and contain large areas that could produce faceted stones.

Topaz crystals are much rarer than the smoky quartz and microcline crystals. Single crystals are known that are 4 in. long. The crystals are usually a bluish color and are clear to highly clouded and fractured. Beautiful sherry- to burgundy-colored topaz crystals have occasionally been found in the Twin Springs pluton south of the Challis sheet.

Beryl crystals (var. aquamarine) occur in several of the granite plutons, most notably in the Sawtooth batholith. The U.S. Bureau of Mines (1968) described most of the beryl occurrences in Idaho. Beryl is also reported from the Crags and the Twin Springs pluton. The aquamarine occurs in the Sawtooths as subhedral to euhedral crystals in vugs, as veinlets along fractures or disseminations in the batholith, and in crystals and massive in pegmatites. Rarely, gem-grade aquamarine occurs in cavities. These crystals could produce beautiful cut stones.

Surprisingly, few large crystals of any mineral have been reported from the Casto pluton, the largest Tertiary granite in the Challis map area. The pluton does contain small miarolitic cavities with numerous, small, euhedral microcline and smoky quartz crystals, but no large cavities or crystals have been reported.

The potential for large-scale production of gem stones from the Sawtooth batholith and other Tertiary granites in Idaho is slight. The occurrences are scattered and access is difficult. Most of the batholiths, including the Sawtooth and Casto plutons, form some of the most scenic areas in the state and are protected as Wilderness or Recreation areas that are withdrawn from mineral entry.

POLYMETALLIC SKARN DEPOSITS

By Theresa M. Cookro, Wayne E. Hall, and S. Warren Hobbs

Polymetallic skarn deposits are defined here as sulfide and (or) iron oxide deposits that have a silicate gangue (including amphiboles, pyroxenes, garnet, and wollastonite) that replaced nearly pure limestone or dolomite with the introduction of silica, iron, and magnesium and ore minerals. Favorable environments for such deposits are along the eastern margin of the Idaho batholith and its satellitic stocks and in calcareous beds in roof pendants within the Idaho batholith.

Examples of skarn deposits within the Challis quadrangle are the Springfield Scheelite mine, the Copper Mountain area (44°20′ N., 115°12′ W.) southeast of Cape Horn Creek, the Blackjack group of claims in the Rapid River area, the Tungsten Jim mine on Thompson Creek, and small tactite bodies that locally contain scheelite and (or) molybdenite in carbonate beds interbedded with argillite in the Salmon River assemblage at the Meadowview mine, Deer Trail mine, Confidence, and Red Robin prospects in the 4th of July Creek area. The Little Boulder Creek deposit in the White Cloud Peaks, although it contains skarn mineralization, is a molybdenum-bearing quartz stockwork deposit and is described elsewhere (Hall, this volume, p. 152).

Tungsten is the principal commodity that has been produced from the skarn deposits in the Challis quadrangle. The Springfield Scheelite mine produced over 5,940 units of WO_3 between 1953 and 1955 (Cater and others, 1973). Tactite containing scheelite and some molybdenite is stockpiled at Tungsten Jim mine. Exploration at the Tungsten Jim mine, in the early 1950′s, resulted in discovery of about 55,000 tons of tungsten ore that had an average grade of about 1.80 percent WO_3 (unpublished DMEA report). As of 1957, approximately 1,500 tons of ore had been mined and processed through a concentration mill. The Blackjack mine produced 2,610 tons of ore that contained 0.06 oz/ton Au, 41.3 oz/ton Ag, 34.1 percent Pb, and 5.8 percent Zn (Cater and others, 1973) from a mineralized shear zone in interbedded marble and shale in a roof pendant in the Idaho batholith.

Descriptive Model

Ore Body

<u>Size</u>: Range from small pods to ore bodies $nx10^3$ ft long; nx10 to $nx10^2$ ft wide; $nx10^2$ ft thick.

<u>Shape</u>: Irregular to pod-shaped or linear. Control by bedding, shearing, and intrusive contacts.

<u>Tonnage and grade</u>: From few tons to $nx10^6$ tons. The grade ranges from 0.32-1.4 percent WO_3; 0.7-13 oz per ton Ag; 0.5-11 percent Pb; 2.3-15 percent Zn; 0.08-1.8 percent Cu; 0.005-0.07 oz per ton Au.

Mineralogy

<u>Ore minerals</u>: scheelite, sphalerite, molybdenite, chalcopyrite, galena.

<u>Gangue minerals</u>: pyrite, pyrrhotite, arsenopyrite, magnetite, quartz.

Major commodities

Tungsten, zinc, copper, lead, silver, trace gold, with or without bismuth

Character of ore

Disseminations, pods, stringers, fracture fillings, or massive ore in quartz and (or) silicified matrix. Ore may be fine to coarse grained.

Weathering products

Weathers to a dark-brown or reddish-brown gossan that may contain secondary lead, zinc, and copper minerals. Residual enrichment of gold may form a low-grade deposit that can be mined for gold.

Lithology of host rock

Impure carbonate rocks. Favorable hosts in the Challis quadrangle are carbonate-bearing roof pendants in the Idaho batholith, fine-grained limy sandstone in the Wood River Formation, clean limestone or carbonaceous micritic limestone interbedded with argillites in black shale host rocks, or carbonate terrane. Close proximity to an intrusive body is required.

Alteration

Carbonate host rocks in roof pendants of the Idaho batholith or adjacent to apical parts of stocks are altered to an iron-magnesium-manganese silicate mineral assemblage that may include diopside-hedenbergite, grossularite-andradite, wollastonite, idocrase, calcite, epidote, chlorite, and quartz.

Geochemical and mineral indicators

Geochemical: W, Zn, Cu, Pb, As, Fe, ± Bi.

Mineral: Skarn mineral assemblage.

Controlling structures

1. Contact between a granitic pluton and carbonate host rock.
2. Bedding, faults, and brecciated rock may be local structural controls.

Resource Assessment

From the descriptive model presented above, recognition criteria are defined; four of these are diagnostic and five are permissive.

Diagnostic criteria

1. Intrusive contact with sedimentary or metasedimentary rocks.
2. Intruded rocks include carbonates.
3. Skarn mineral assemblage.
4. Geochemical anomaly of any or all of the following: W, Zn, Cu, Pb, Mo.

Permissive criteria

1. Metamorphism of intrusive rock and (or) skarn assemblage.
2. Scheelite and (or) garnet in panned concentrates.
3. Presence of gossan.
4. Silicification.
5. Near intrusive contact below regional thrust fault.

From the above criteria we have identified 13 areas that have a potential for polymetallic skarn deposits (pl. 12) and have scored these areas as shown on table 29. From these scores we interpret the resource potential of the areas as follows.

High potential: areas 3, 8, 11, and 13.

Moderate potential: areas 2 and 4.

Low potential: areas 1, 5, 6, 7, 9, 10, and 12.

Area 3 has extensive skarn zones in Washington Basin ($44^{o}02'$ N., $114^{o}41'$ W.), Fourth of July Basin ($44^{o}03'$ N., $114^{o}39'$ W.), and in the Tungsten Jim mine area (pl. 12). Scheelite in skarn at the Little Boulder Creek deposit

Table 29. Recognition criteria for polymetallic skarn deposits (see pl. 12)

Map area	Diagnostic: Intrusive contact with sedimentary or meta-sedimentary rocks	Diagnostic: Intruded rocks include carbonates	Diagnostic: Skarn mineral assemblage	Diagnostic: Geochem. anomaly W±Zn±Cu ±Pb±Mo	Total	Permissive: Retro-grade metamor-phism	Permissive: Scheelite and (or) garnet in panned concentrate	Permissive: Presence of gossan	Permissive: Silici-fication	Permissive: Near intru-sive under regional thrust fault	Total	Resource potential
1	-1	-1	-1	0	-3	-1	-1	0	-1	-1	-4	Low
2	1	1/2	1/2	0	2	0	0	1/2	0	1	1 1/2	Moderate
3	1	1	1	1	4	1	1	1/2	1	1	4 1/2	High
4	1/2	1/2	1/2	0	1 1/2	0	0	1/2	1/2	-1	0	Moderate
5	-1	-1	-1	0	-3	-1	-1	-1	-1	-1	-5	Low
6	-1	0	0	0	-1	0	0	1/2	-1	-1	-1 1/2	Low
7	-1	1/2	-1	-1	-2 1/2	-1	0	0	-1	-1	-3	Low
8	1	1	1/2	0	2 1/2	1	0	1/2	1	-1	1	High
9	-1	-1	-1	0	-3	0	0	0	0	-1	-1	Low
10	0	1	0	0	1	0	0	0	0	0	0	Low
11	1/2	1	0	1	2 1/2	0	0	1/2	1	1/2	2	High
12	-1	1	-1	0	-1	-1	-1	0	-1	-1	-4	Low
13	1	1	1/2	0	2 1/2	0	0	1/2	0	0	1/2	High

(see Hall, this volume, p. 152) constitutes an explored but undeveloped resource. Other areas of skarn alteration are present around the White Cloud stock. Areas 8, 11, and 13 contain roof pendants that have skarn alteration. Area 8 contains the Springfield Scheelite mine, which has a recorded production of scheelite. Area 11 contains the base-metal deposits in the Bayhorse district. Skarn deposits are not known, but would be likely if there are areas where the Juliette stock (44°24′ N., 114°22′ W.) is in contact with carbonate rocks.

Areas 2 and 4 are ranked as having moderate potential. They contain scattered outcrops of metasedimentary rocks and roof pendants, but these are less intensely mineralized than the deposits in areas ranked as having high potential.

REPLACEMENT AND SHEAR ZONE RARE-EARTH MINERAL OCCURRENCES

By Theresa M. Cookro

The rare-earth mineral rhabdophane and trace amounts of monazite were found in small amounts within a fault zone in the Murphy Peak area of Monumental Summit (Adams, 1968; Cater and others, 1973). The north(?)-trending shear zones cut a calcareous metasedimentary unit of the Precambrian Yellowjacket Formation and the granodiorite of the Idaho batholith. The rhabdophane and monazite are in an earthy brown to red to yellow brown oxidized part of the fault zone with limonite, manganese oxides, clays, coarse euhedral quartz, chalcedony, pyrite, calcite, and also trace cinnabar, rutile, and zircon. Rare-earth elements, arsenic, manganese, iron, zinc, silica, and barium are present in greater amounts within the shear zone than in the non-sheared metasedimentary rock.

The U.S. Bureau of Mines estimated that the Monumental Summit rare-earth mineral occurrence contains 95,000 tons of material with an average grade of 7.2 pounds of rare-earth elements per ton (Cater and others, 1973, p. 98). The calcareous metasedimentary rocks have been intruded by the Idaho batholith and dissected by shear zones, and it is possible that other rare-earth mineral occurrences of this type are present in the quadrangle.

IRREGULAR REPLACEMENT DEPOSITS OF BASE AND PRECIOUS METALS

By S. Warren Hobbs, Frederick S. Fisher, and Kathleen M. Johnson

Nearly all of the base- and precious-metal replacement ore deposits in the Challis quadrangle have formed by the selective replacement of carbonate strata that make up the Bayhorse Dolomite, the Ella Dolomite, and the Saturday Mountain Formation of Ordovician to Cambrian age. The main exposures of these strata are in the southeastern part of the Challis quadrangle, although scattered roof pendants in the Idaho batholith in the central and western part of the quadrangle contain some carbonate strata that may be correlative with these formations in the Bayhorse area. Small occurrences and numerous prospects have been described from these roof pendants (Umpleby, 1913b; Leszcylowski and others, 1983; Lowe and others, 1983; Ridenour and others, 1983), but none has had significant production. The carbonate part of the Proterozoic Yellowjacket Formation contains no known deposits of this type although carbonate-bearing members of these strata in the Yellowjacket district, as well as those in the Yellow Pine district, are possible hosts for such deposits.

Past production from base- and precious-metal replacement ore bodies in the Challis quadrangle is shown on table 30 and includes all available data from the earliest discoveries to 1984. Many early records were poorly kept and sources of ore were ambiguous. As a consequence, the amounts and value of the commodities are generalized. Although much production was made in the late 1800's and early 1900's from the Beardsley-Excelsior, Pacific, and Riverview mines on Bayhorse Creek (pl. 13), and the Red Bird and South Butte mines on Squaw Creek (pl. 13), more than 85 percent of the total silver production and nearly 80 percent of the lead has come from the Clayton Silver mine on Kinnikinic Creek (pl. 13). This mine, the only one still operating in 1985, has produced ore on a modest scale with only minor interruptions from the mid 1920's. Several of the past productive properties as well as previously located prospects have been the object of active study and exploration in recent years. All of these deposits are considered to be related to the Idaho batholith and probably of Late Cretaceous age.

Descriptive Model

Ore Body

Size and shape: Range from small pods a few feet or less in major dimension to more or less continuous, usually irregular, replacement bodies that may be $nx10^2$-$nx10^3$ ft long, and range in thickness from n-$nx10^2$ ft. Width may equal length but is usually much less, resulting in generally elongated lenses or ovoid pipe-like bodies that roughly follow the bedding of the carbonate host rock. Many ore shoots are extremely irregular as at the Beardsley and Excelsior mines where the deposit comprises numerous veinlets along fractures and bunches of ore that range in size from that of baseballs to masses 15 or more feet in diameter, distributed along a more or less continuous zone that is usually controlled by bedding. In the Red Bird mine, some of the ore bodies are described by Bell (1913) as pipe-shaped or oblong in plan with dimensions of 60-80 ft long, 20-30 ft wide, and 400 ft deep.

Tonnage and grade: Because of the irregular nature of the ore deposits and the complex controls of deposition, the estimates of tonnage range from a few tons as found in many prospects to $nx10^5$ tons of low grade or marginal ore. Grade ranges from a few percent lead and zinc and a few ounces of silver per ton to 30-40 percent lead and 40-60 oz of silver per ton. Silver to lead ratios are highly variable, but generally exceed 1 oz of silver to 1 percent of lead.

Mineralogy

Ore minerals: Primary sulfide ore restricted to galena, sphalerite, tetrahedrite, and minor chalcopyrite. Secondary oxide ore contains cerussite, anglesite, cerargyrite, and smithsonite as the preponderant components.

Gangue minerals: Quartz, barite, calcite, fluorite, pyrite.

Major commodities

In order of decreasing value: Silver, lead, zinc, copper, and gold.

Character of ore

Disseminations, massive replacement of carbonate strata by sulfide ore minerals in the form of pods, lenses, or irregular bodies that range widely in size and shape. Locally, as at the Pacific and Riverview mines, the ore bodies include breccia filling and replacement of breccia fragments. Where deeply weathered and oxidized, the sulfides are converted to masses of granular carbonates and sulfates of lead and zinc

Table 30. Production of base and precious metals from irregular replacement ore deposits in the Challis quadrangle

	Gold	Silver	Copper	Lead	Zinc
Amount----------------	2,612 oz	7,604,480 oz	784 tons	52,320 tons	14,160 tons
Approximate value using average prices for main periods of production-------	$121,000	$11,000,000	$376,000	$10,250,000	$3,059,000

with silver chloride. The oxide ore bodies generally conform to the shape of the original replacement deposits; where they are mined to depth, as at the Red Bird mine, they grade into the sulfide ore zone.

Alteration and weathering

Local dolomitization in vicinity of ore bodies; possibly the more extensive development of dolomite in the carbonate strata close to known mines is related to ore deposition. No other pervasive hydrothermal alteration related to the ore deposition has affected the ore bodies or host rock. The disconformity between the Ramshorn Slate and the underlying Bayhorse Dolomite has been a channelway for fluids that at various times dissolved the dolomite and produced breccias and concentrations of residual sand and clay. Surface exposures of mineralized zones weather to light yellow or red iron oxide or black manganese oxides.

Lithology of host rocks

Irregular replacement of carbonate strata by base and precious metal deposits is predominantly in the Bayhorse Dolomite, the Ella Dolomite, and the Saturday Mountain Formation. All of the host rocks are calcareous or dolomitic and all contain various amounts of sand or silt either as pervasive impurities or as widely spaced layers or zones of fine sand or silt. Bedding in the carbonate rocks ranges from thin to thick or massive; some beds are finely laminated. In some places these siltstone or calcareous siltstone zones have served to guide ore-bearing solutions and have influenced the localization of the ore deposits. The Garden Creek Phyllite and Ramshorn Slate underlie, are in fault contact with, or are interbedded with carbonate units and may have been source rocks for metallic elements.

Controlling structures

1. Anticlinal folds in which an impervious shale zone serves to trap ore solutions in underlying carbonate strata.
2. Steep faults, shear zones, and brecciated zones that cut the carbonate strata and serve both as channels for ore-bearing solutions and as sites of deposition.
3. Thrust faults that bring impervious terrane over the reactive carbonate host rocks and dam the ore-bearing solutions beneath the allochthon or provide new zones of porosity at the fault contact.

Geochemical and mineral indicators:

1. Geochemical anomalies of lead, zinc, silver, and copper in soil samples over surface location of steep faults.
2. Mineral indicators: Galena, sphalerite, and tetrahedrite in country rock, soils, or stream sediments.

Resource Assessment

From the descriptive model above, we define seven recognition criteria, of which we consider three to be diagnostic and four to be permissive.

Diagnostic criteria

1. Presence of carbonate strata.
2. Steep north-trending faults.
3. Evidence of base- and precious-metal mineralization. May be either geochemical anomalies, mines, or prospects.

Permissive criteria

1. Contiguous black shale terrane lithology.
2. Overlying thrust faults.

3. Contiguous intrusive rocks.
4. Gossans.

Evaluation of the diagnostic criteria (table 31) was used to divide the quadrangle into 15 areas (pl. 13). Each area has been scored and ranked as to its potential--high, moderate, or low--for resources of base- and precious-metal replacement deposits. Area number 1 on the map was not scored because no carbonate units were mapped in these areas, and carbonate units are essential for the formation of base and precious metals in replacement deposits. No deposits of this type are expected in area 1.

Areas 10, 11, and 12 are considered to have high potential for the discovery of at least one additional ore deposit comparable to the Red Bird mine in area 10, the Clayton Silver mine in area 11, and the Excelsior or River View in area 12. All of these areas have a high combination of diagnostic and permissive criteria that support such a probability. Areas 3, 5, and 9 are lacking in some of the criteria and are rated as having a lower probability for the discovery of major ore deposits. Areas 3 and 5 occur as roof pendants in the Idaho batholith and are composed only partly of carbonate rocks. Their limited extent and lack of steep faults detract from their favorability. Area 9 has the highest numerical rating of the three but is only a small outcrop surrounded by the Challis Volcanic Group, which makes any evaluation difficult. Absence of one or more of the diagnostic criteria in areas 2, 4, 6, 7, 8, 13, 14, and 15 together with deficiencies in the permissive criteria suggest that there is little or no probability for the occurrence of any significant base- and precious-metal replacement deposits in these areas.

MERCURY REPLACEMENT DEPOSITS

By B.F. Leonard and Theresa M. Cookro

Mercury occurs as cinnabar in replacement deposits in the north-central part of the Challis quadrangle. Host rocks are calcareous metasedimentary rocks intruded by Cretaceous and Tertiary granitic rocks. Cinnabar occurs in chalcedonic quartz replacing the metasediments. High-angle faults trending N. 30° E. or N. 30-50° W. are thought to control emplacement of ore minerals.

Examples of this deposit type include the Fern, Hermes, and Pretty Maid mines (pl. 14) in the Yellow Pine district. At the Fern mine, chalcedonic seams with cinnabar strike about N. 35° E. through calcic marble. Total recorded production is 27 76-lb flasks of mercury in 1917-18 (unpublished records, U.S. Bureau of Mines, Spokane, Wash.). Ore at the Hermes mine, the largest producer of mercury in the district, occurs in tabular pipes most commonly found in brecciated and silicified zones. Total production was about 16,000 flasks between 1921 and 1966 (Minerals Yearbook cumulative data and James Ridenour, U.S. Bureau of Mines, oral commun., 1983). Ore from the Pretty Maid mine shows finely granular cinnabar replacing black quartzite. Leonard estimates that the Pretty Maid mine yielded 200-300 flasks of mercury. The total value of the mercury produced from the district, in current dollars at the time of production, is approximately $3 million (unpublished records, U.S. Bureau of Mines, Spokane, Wash.)

This report is taken from work by the authors at the three known deposits and from reports by Bradley (1943), Currier (1935), Livingston (1919), Larsen and Livingston (1920), and Schrader and Ross (1926). Also the surface and underground geology of the Hermes mine was mapped in 1942 by A.E. Granger and A.F. Shride of the U.S. Geological Survey. The results of the mapping,

Table 31. Recognition criteria for irregular replacements of base and precious metals (see pl. 13)

Map area	Diagnostic: Carbonate rocks	Diagnostic: Steep north-trending faults	Diagnostic: Evidence of base- and precious-metal mineralization	Total	Permissive: Contiguous black shale terrane lithology	Permissive: Overlying thrust faults	Permissive: Contiguous intrusive rocks	Permissive: Gossans	Total	Resource potential
1	(See text)									None
2	1	0	1/2	1 1/2	1/2	0	1	0	1 1/2	Low
3	1	0	1	2	0	0	1	0	1	Moderate
4	1	0	1/2	1 1/2	1	0	1	0	2	Low
5	1	0	1	2	1	0	1	0	2	Moderate
6	1	0	1/2	1 1/2	0	0	1	0	1	Low
7	1	0	0	1	0	0	1	0	1	Low
8	1	0	0	1	0	0	1	0	1	Low
9	1	1/2	1	2 1/2	1	1	1	1/2	3 1/2	Moderate
10	1	1	1	3	1/2	1	1/2	1/2	2 1/2	High
11	1	1	1	3	0	1	1/2	1	2 1/2	High
12	1	1	1	3	1	1	1	1/2	3 1/2	High
13	1	1/2	0	1 1/2	-1	0	0	0	-1	Low
14	1	1/2	0	1 1/2	-1	0	0	0	-1	Low
15	1	1/2	1/2	2	-1	0	0	0	-1	Low

supplemented by additional work, were summarized by Granger (written commun., 1945). A generalized version of Granger and Shride's surface map was published by the U.S. Bureau of Mines (1943, fig. 3) in a report which also considers problems encountered in mining and milling Hermes ore.

Descriptive Model

Ore Body

Size: nx10-nx10^2 ft wide; nx10^2-nx10^3 ft long; nx10-nx10^2 ft thick

Shape: Irregular-shaped, chimney-like masses.

Tonnage and grade: Up to nx10^5 short tons of ore. Average grades are about 3 lbs Hg/ton of ore.

Mineralogy

Ore minerals: Cinnabar

Other minerals: Trace electrum, quartz, chalcedony, sericite, pyrite, arsenopyrite, trace stibnite, dickite, kaolinite(?), montmorillonite, mixed layer clays with chalcedony and k-feldspar, vugs containing reddish chert or jasper.

Cinnabar (Schrader and Ross, 1926) occurs as small irregular grains and thin coatings on pyrite grains and on surfaces and fillings of small open spaces, in narrow seams and fractured jasperoid. Pyrite (Granger, written commun., 1945) is disseminated in the deposit; it is earlier than cinnabar and often has cinnabar coatings. Orpiment(?), pararealgar(?), realgar, and stibnite are found in trace amounts. Native sulfur is found locally and encrusts and (or) is intergrown with realgar.

Samples from the Pretty Maid mine examined by Leonard had finely granular cinnabar, sparingly disseminated with replacement textures in fine-grained, locally calcareous, black quartzite. The cinnabar crystals are small, mostly less than 0.1 mm. Rutile grains are also present. Another ore sample consisted of a vuggy aggregate of clay-sized chalcedony with patchy quartz displaying cockscomb textures. Cinnabar is found in colliform bands. At the Fern mine chalcedony veins cut weathered calcic marble in which sparse porphyroblasts, formerly tremolite or actinolite, are pseudomorphed by a very fine grained aggregate of carbonate, chalcedony, clay, and limonite.

Commodities

Mercury

Alteration

Mostly silicification and argillization; clay was so abundant at the Hermes it caused mining and milling problems (U.S. Bureau of Mines, 1943). Hydrothermal alteration in the Fern Creek area produced clay minerals, chalcedony, and pyrite regionally in small amounts.

Character of the ore

The best ore (Granger, written commun., 1945) occurs in tabular pipes arranged along parallel bands. The ore is disseminated but is more common in the brecciated and silicified zones, and at the Hermes mine is limited in depth on the south side by a large aplite dike.

Lithology of host rocks

The district has a series of tilted metasediments consisting of quartzites, limestones, and schists intruded by Cretaceous granites and granodiorites, quartz porphyries, and aplitic dikes, and Tertiary rhyolitic dikes. The metasedimentary rocks trend northwest and dip

60^{o}-85^{o} NE. They are within a northwest-trending fold belt. The metasedimentary rocks were thought to be Paleozoic by a number of early authors but are now considered by Leonard, based on regional stratigraphic and structural studies, to be Precambrian and equivalent to the Yellowjacket and Hoodoo Formations. Historically, authors have called these rocks Paleozoic because the only carbonate rocks known in the region at that time were of that age. Lewis and Lewis (1982) identified elongate, ribbed, tubular, iron-stained forms found by geologists of the Superior Mining Co. in massive dolomitic limestone as Halysites chain corals, and concluded that the rock was Ordovician. Michael Taylor (USGS, written commun., 1982) was unable to find any fossils in the original sample. Leonard examined thin sections of the samples and believes the forms to be pseudomorphs of chalcedony, carbonate, and goethite after porphyroblasts of amphibole, probably tremolite or actinolite. The present evidence is not sufficient to support either a Precambrian or a Paleozoic age for the metasedimentary rocks.

Controlling structures

N. 30^{o} E. slip faults predominate (Fern mine) and the strike of the chalcedonic seams with cinnabar is about N. 35^{o} E. Dip is NW (Schrader and Ross, 1926; Livingston, 1919). The cinnabar at the Hermes mine (Granger, written commun., 1945) is largely confined to sheared, brecciated, and strongly hydrothermally altered limestone made up of thick-bedded, cream, buff, and gray, coarsely crystalline limestone and dolomite about 110 ft thick, striking N. 45^{o} W. with near-vertical bedding.

Geochemical and mineral indicators

Hg, Sb, As anomalies, cinnabar, and chalcedonic quartz.

Resource Assessment

From the descriptive model presented above, eight recognition criteria are defined; four of these are diagnostic and four are permissive.

Diagnostic criteria

1. Presence of calcareous metasedimentary rocks
2. Presence of cinnabar
3. Presence of high-angle faults, especially with N. 30^{o} E. or N. 30^{o}-50^{o} W. trends
4. Presence of jasperoid or chalcedonic quartz or areas of intense silicification

Permissive criteria

1. Within 5 mi of the edge of a caldera
2. Presence of geochemical anomalies of Hg, Sb, or As
3. Presence of some sericitic alteration
4. Presence of abundant clay minerals

On the basis of the above-described criteria, nine areas in the quadrangle were identified as having potential for mercury replacement deposits (pl. 14). Each area was scored as shown on table 32. Our subjective interpretation of the resource potential in the nine areas (pl. 14) for mercury replacement deposits is as follows:

High potential: area 3

Moderate potential: area 2

Low potential: areas 1, 4, 5, 6, 7, 8, and 9

Table 32. Recognition criteria for mercury replacement deposits (see pl. 14)

Map area	Diagnostic					Permissive					
	Presence of calcareous metasedimentary rocks	Presence of cinnabar	Presence of high angle faults, especially with N. 30° E. or N. 30-50° W. trends	Presence of jasperoid or chalcedonic quartz or areas of intense silicification	Total	Within 5 miles of the edge of a caldera	Presence of geochemical anomalies of Hg, Sb, or As	Presence of some sericitic alteration	Presence of abundant clay minerals	Total	Resource potential
1	1/2	0	0	0	1/2	-1	1/2	0	0	- 1/2	Low
2	1	1/2	1/2	1/2	2 1/2	-1	1	1/2	1/2	1	Moderate
3	1	1/2	1	1/2	3	1	1	1/2	1/2	3	High
4	0	1/2	1/2	1/2	1 1/2	- 1/2	1/2	1/2	1/2	1	Low
5	1	0	0	0	1	-1	1/2	0	0	- 1/2	Low
6	1/2	0	1/2	0	1	1	0	0	0	1	Low
7	1/2	0	1/2	1/2	1 1/2	- 1/2	1/2	1/2	0	1/2	Low
8	1/2	1/2	0	0	1	1	0	0	0	1	Low
9	-1	0	1/2	1/2	0	1/2	1/2	1/2	1/2	2	Low

Area 3 contains the Hermes, Pretty Maid, and Fern mines. Area 2 has similar lithologies, alteration types, Hg, Sb, and As anomalies as well as the presence of the mineral cinnabar. The carbonate terrane of area 6 is near the edge of a caldron complex, and area 4 defines other localities on the quadrangle where cinnabar has been recorded historically. The largest block marked on the map for area 4 has reported cinnabar with gold in quartz veins.

ZEOLITE DEPOSITS IN TUFFACEOUS ROCKS

By Frederick S. Fisher and Kathleen M. Johnson

Zeolite minerals occur in the Twin Peaks caldera (fig. 2) in a zone over three-quarters of a mile wide and eight miles long spanning the boundary between the structurally intact southeastern part of the caldera and the complexly fractured and faulted northwestern block. The zeolites are found in the lower cooling unit of the tuff of Challis Creek, which is a moderately to densely welded, crystal-rich, pumiceous, rhyolitic ash-flow tuff, and in the nonwelded, crystal-poor matrix of caldera wall slump debris. Total thickness of these units is in excess of 1,500 ft.

Zeolitically altered rocks are bleached to pale green and buff colors and commonly do not support extensive vegetation. Mordenite and clinoptilolite have been identified by X-ray methods. Zeolites can be recognized in thin section as replacements of glass shards and pumice fragments (Hardyman, 1985).

Isolated patches of zeolitically altered rock also occur in tuffs both within and outside the caldera margins. In places, such as near Mosquito Flat Reservoir, these rocks are associated with intrusive rhyolite (Hardyman, 1985).

Hardyman (1985) suggests that the alteration is due to large volumes of hydrothermal fluids circulating within the medial fault system. Criss and others (1984) point out that these rocks have only moderate ^{18}O depletions and are situated on the fringe zones of a large Tertiary hydrothermal system developed around the Casto pluton. It is also possible that the zeolites are an open-system deposit (Sheppard, 1973), in which zeolitization was the result of the reaction of volcanic glass with subsurface water that originated as meteoric water. Steven and Van Loenen (1974) suggest a similar diagenetic origin for zeolitic tuff beds in the Creede Formation in the San Juan volcanic field, Colorado.

Using the dimensions given above, we estimate that the potential tonnage of zeolitized rock is at least several billion tons. The grade of these rocks is unknown, but zeolites are abundant both in hand specimens and in thin sections of rocks from throughout the altered zone. Based on these observations, we believe that a zeolite resource may exist in the Twin Peaks caldera; the areal extent of altered rock suggests that the deposit could be large. Such a resource could be established only by drilling and testing a large volume of rock.

Glass-rich tuffs are abundant throughout the eastern part of the Challis quadrangle. It is likely that other areas of zeolite have not been recognized because of the difficulty of identifying zeolites in the field. For this reason, we speculate that there could be a considerable, but presently unknown, zeolite resource elsewhere in the quadrangle.

PRECIOUS-METAL DEPOSITS IN EPICLASTIC SEDIMENTS

By Frederick S. Fisher and Kathleen M. Johnson

This type of ore deposit has only one known representative in the Challis quadrangle--the Dewey mine (pl. 15) in the Thunder Mountain district. Ores at the Dewey mine are present in black, carbonaceous mudflow breccia and volcanic sandstone and conglomerate. They occur in these rocks mostly as fine grains and as filaments in seams and cracks. Historic production of gold from the Dewey mine was approximately 14,381 oz, in the period 1902-1958. Silver production during the same period was 8,612 oz (unpublished records of U.S. Bureau of Mines, Spokane, Wash.). The presence of geologic features elsewhere in the quadrangle that are similar to those that controlled ore deposition at the Dewey mine suggests that other such deposits may exist.

Descriptive Model

Ore Body
- Size: 765 ft long x 200 ft wide x 140 ft thick.
- Shape: Bedded, stratabound, planar.
- Tonnage and grade: 1,428,000 tons at 0.13 oz Au/ton (Cater and others, 1973, p. 73).

Mineralogy
- Ore minerals: Gold, silver, electrum, pyrargyrite
- Gangue minerals: Pyrite, clays, rock fragments, carbon trash

Commodities
- Gold, silver

Character of ore
- Ore minerals concentrated in seams, cracks, and bedding plane laminations. Gold is fine grained, mostly <0.1 mm; rare leaves or aggregates to several millimeters. Gold ranges from approximately 550 to 950 fine (B.F. Leonard, oral commun., 1985).

Lithology of host rocks
- Highest grade and most consistent ores occur in black, carbonaceous mudflow breccia. Gold and silver also occur in rocks described as volcanic conglomerate, volcanic sandstone, and carbonaceous volcanic sandstone. Leonard and Marvin (1982, p. 25) describe the Dewey beds as consisting of "water-laid volcanic conglomerate, volcanic sandstone, mudstone, carbonaceous shale, a little lignite, and at one place lake beds of laminated carbonaceous mudstone and air-fall(?) tuff."

Controlling structures and other features
1. Presence of black carbonaceous material, particularly where brecciated.
2. Ore appears to be concentrated along a fault striking about east to N. 30° W. (Shenon and Ross, 1936, p. 39).
3. Ore is found in small-scale cracks, not distributed evenly through the rock.

Geochemical and mineral indicators
- Geochemical: Au, Ag, As
- Mineral and other: pyrite, carbon trash

Resource Assessment

From the descriptive model above, we define ten recognition criteria, of which we consider four diagnostic and six permissive.

Diagnostic criteria

1. Evidence of precious metal mineralization. This may be either geochemical anomalies, mines or prospects, or placer deposits.
2. Within volcanotectonic subsidence structures.
3. Presence of epiclastic sediments.
4. Presence of carbon trash.

Permissive criteria

1. Shearing associated with high-angle faults.
2. Presence of pyrite.
3. Presence of anomalous arsenic.
4. Extensive areas of oxidized rock and limonitic soils.
5. Proximity to gold-silver mineralization.
6. Proximity to high-angle structures.

We plotted the areal distribution of these criteria and divided the map into six classes of areas (pl. 15). The six classes were then scored and ranked for their potential for deposits similar to the descriptive model (table 33). In the area labeled 1 no epiclastic sediments are known to exist. By definition, epiclastic sediments are essential for the existence of this deposit type; therefore we did not score area 1 for potential for resources of this deposit type. Areas labeled 6 are ranked as having a high resource potential. We believe that there is a high probability that at least one additional deposit similar to the Dewey deposit is present in the areas labeled 6. The areas labeled 5 are ranked as having moderate potential. All of the diagnostic criteria are widespread in area 5 except that nowhere have we found epiclastic sediments containing carbonaceous material in quantities analogous to the sediments that host the Dewey mine. If areas with adequate amounts of carbon were found to exist, we would rank them as having high potential for these deposits. Lacking that information, we believe that the probability of finding a deposit similar to the Dewey deposit is not great. In areas labeled 2, 3, and 4 there is little or no chance for finding a precious metal deposit in epiclastic sediments, and these areas are ranked as having a low potential.

PRECIOUS-METAL DEPOSITS IN VOLCANIC TUFFS

By Frederick S. Fisher and Kathleen M. Johnson

The deposit at Sunnyside mine, in the Thunder Mountain district, is the only known representative of this ore deposit type. Precious metals in the Sunnyside deposit occur in fractures and cracks in the upper, nonwelded parts of the Tertiary Sunnyside tuff. Ore minerals are fine grained, and highest grade shoots are concentrated beneath clay-rich beds along a northeast-striking fracture zone. Host rocks are extensively fractured, oxidized, and stained with iron oxides. Sulfide minerals are sparse.

The Sunnyside tuff is a crystal-rich rhyolite. Away from the Sunnyside mine area it is red to red-brown, densely welded, and devitrified. It is a multiple-flow compound cooling unit that contains numerous small volcanic rock fragments and well-flattened pumice lapilli throughout. In the vicinity of the mine, the top of the unit (which contains most of the mineralized rock) is characterized by abundant (10-15 percent) rounded pumice fragments that are

Table 33. Recognition criteria for precious-metal deposits in epiclastic sediments (see pl. 15)

Map area	Diagnostic					Permissive							
	Evidence of precious metals	Within volcano tectonic subsidence structures	Presence of epiclastic sediments	Presence of carbon trash	Total	Shearing	Pyrite	Anomalous As	Extensive zones of oxidized rock	Proximity to gold-silver mineralization	Proximity to high-angle structures	Total	Resource potential
1	(see text)												None
2	1/2	-1	1	0	1/2	0	1/2	1/2	0	1/2	1	2 1/2	Low
3	0	-1	1	1/2	1/2	0	1/2	0	0	0	1	1/2	Low
4	0	1	1	0	2	0	1/2	1/2	1/2	1/2	1	2	Low
5	1	1	1	1/2	3 1/2	1/2	1/2	1/2	1/2	1	1	4	Moderate
6	1	1	1	1	4	1	1/2	1/2	1/2	1	1	4 1/2	High

only slightly flattened. Modal analysis of the Sunnyside tuff near the ore bodies shows a total phenocryst content of 15-40 percent. Quartz is 35-48 percent of total phenocrysts; sanidine 50-70 percent; biotite 0-3 percent; and zircon, apatite, and opaque minerals comprise less than 1 percent.

Total gold and silver production from the Sunnyside mine is 5,237 oz and 3,909 oz, respectively (U.S. Bureau of Mines, Spokane, WA, file information). All production was prior to 1938. The property was being drilled and actively explored in 1984 (J.R. Mangham, written commun., 1985).

Descriptive Model

Ore Body

Size: nx10 to nx10^2 ft wide; nx10 to nx10^2 ft long; up to 30 ft thick (averaging 10-15 ft)

Shape: Bedded, stratabound, planar.

Tonnage and grade: 2,291,000 tons at 0.14 oz gold and 0.36 oz silver per ton (Cater and others, 1973, p. 88).

Mineralogy

Ore minerals: Gold, silver, electrum (gold/silver ratio about 1:3). Silver also present as sparse acanthite and naumannite. Some molybdenum present in ilsemannite.

Gangue minerals: Pyrite, arsenopyrite, clay, jarosite, sericite, illite, quartz.

Commodities

Gold, silver

Character of ore

Gold is very fine grained (<0.1 mm) and occurs in fractures and cracks. Shenon and Ross (1936, p. 41) report that the better ore appears to be concentrated along north- to northeast-trending, vertically dipping fracture zones. Rocks within the ore body are extremely fractured and oxidized; clay minerals are abundant. Drusy quartz is common along fractures. Pyrite is sparse.

Lithology of host rocks

The bulk of the ore body is blanketlike and is hosted in the nonwelded top of the Sunnyside tuff. These rocks are overlain by volcaniclastic sandstone, conglomerate, mudflow breccia, and shale.

Controlling structures and other features

1. Ore is mostly concentrated in highly fractured, non-welded, porous rhyolite beneath much less permeable mudstone and clay-rich beds (Shenon and Ross, 1936, p. 41; Umpleby and Livingston, 1920, p. 5).
2. Richest ores are associated with vertical northeast-striking fracture zones (Shenon and Ross, 1936, p. 41).
3. Ore is found in fractures and is not evenly distributed throughout rock.
4. Extensive development of argillically altered rocks is common throughout the deposit.

Geochemical and mineralogical indicators

Geochemical: Au, Ag, As, and Mo are commonly concentrated in rocks within and near the ore zone. Cu, Sb, Zn, and W are much less common but do occur in anomalous concentrations in isolated samples of drill core from the mine area (Cater and others, 1973, p. 83; F.S. Fisher, unpublished data).

Mineralogical: clay minerals, sericite, illite, Fe oxides.

Resource Assessment

From the descriptive model above, we define nine recognition criteria, of which we consider four diagnostic and five permissive.

Diagnostic criteria

1. Evidence of precious-metal mineralization. This may be either geochemical anomalies, mines or prospects, or placer deposits.
2. Within volcanotectonic subsidence structures.
3. Presence of non-welded rhyolitic tuff.
4. Near (within 2 mi of) high-angle faults.

Permissive criteria

1. Extensive fracturing.
2. Presence of anomalous As and (or) Mo.
3. Extensive zones of oxidized rock.
4. Presence of impermeable or semipermeable barriers (rock or mineral units) that would allow ponding of migrating fluids or alter flow patterns, pH, and temperature of solutions.
5. Proximity to gold mineralization.

Based on the descriptive model and diagnostic criteria, the quadrangle was divided into 111 areas (pl. 16). Each area was then scored and ranked as to its potential for resources of precious metals in volcanic tuffs (table 34). Areas indicated on plate 16 as number 1 were not scored because no volcanic tuffs were mapped in any of these areas. Because volcanic tuffs are essential for the occurrence of these deposits, areas labeled 1 are considered to have no potential for deposits analogous to the Sunnyside mine.

Areas 4, 9, 10, 19, 82, and 89 were ranked as having a high potential. This is to say that we believe the combination of diagnostic and permissive criteria indicates a high probability that at least one additional ore deposit comparable to the Sunnyside mine exists in each of these areas. There is a lower probability that one or more deposits exists somewhere in areas 3, 5, 44, 52, 67, 68, 72, 85, and 86. The absence of some of the diagnostic criteria in the remaining areas suggests that there is little or no probability of the occurrence of a deposit similar to the Sunnyside model in those areas.

STRATABOUND, STRATIFORM BRECCIA-CONTROLLED FLUORSPAR DEPOSITS IN CARBONATE ROCKS

By S. Warren Hobbs

All known fluorspar deposits of this category in the Challis quadrangle are associated with the upper part of the Bayhorse Dolomite in the Bayhorse mining district. Fluorite also occurs, however, as veins, fracture fillings, and as a minor gangue mineral in base-metal deposits and some precious-metal deposits both in the Bayhorse area and throughout the quadrangle. At least two veins in the Bayhorse area, the Chalspar No. 1 and the Past-up vein, are fracture fillings in the dolomite and have had some small production in the past. These and probably others may have been feeder channels for the major breccia-filling deposits near the top of the Bayhorse Dolomite. Small amounts of fluorite occur as a part of the gangue at the Red Bird mine in the Saturday Mountain Formation, and in the Clayton Silver mine in the Ella Dolomite. Fluorite-bearing veins in the Challis Volcanics at Meyers Cove, about 27 mi north of the Bayhorse district, have been extensively mined in the past, and scattered small fissure-filling veins in the Idaho batholith and in small roof

Table 34. Recognition criteria for precious-metal deposits in volcanic tuffs (see pl. 16)

Map area	Diagnostic: Evidence of precious metals	Diagnostic: Within volcanotectonic subsidence structures	Diagnostic: Presence of nonwelded rhyolitic tuff	Diagnostic: Proximity to high-angle faults	Total	Permissive: Fracturing	Permissive: Anomalous As and (or) Mo	Permissive: Extensive zones of oxidized rock	Permissive: Presence of impermeable barriers	Permissive: Proximity to gold mineralization	Total	Resource potential
1	see text				0							None
2	1	1	0	1/2	2 1/2	1/2	1	1/2	0	1/2	2 1/2	Low
3	1/2	1	1	1/2	3	0	1/2	0	1/2	1/2	1 1/2	Moderate
4	1	1	1	1	4	1/2	0	0	1/2	1	2	High
5	1/2	1	1	1/2	3	0	0	0	1/2	1/2	1	Moderate
6	0	1	0	1/2	1 1/2	0	0	0	0	0	0	Low
7	1/2	1	0	1/2	2	1/2	1/2	0	0	1/2	1 1/2	Low
8	0	1	1	1/2	2 1/2	0	0	0	0	0	0	Low
9	1	1	1	1/2	3 1/2	0	1/2	0	0	1/2	1	High
10	1	1	1	1	4	1/2	1	1/2	1/2	1	3 1/2	High
11	0	1	0	0	1	0	0	0	0	0	0	Low
12	1/2	1	0	1/2	2	0	0	0	0	0	0	Low
13	0	1	0	0	1	0	0	0	0	0	0	Low
14	0	1	0	0	1	0	0	0	0	0	0	Low
15	1/2	1	1	0	2 1/2	0	0	0	1/2	0	1/2	Low
16	1/2	1	0	1	2 1/2	1/2	1/2	1/2	0	1/2	2	Low
17	0	1	1	0	2	0	0	0	1/2	0	1/2	Low
18	0	1	1	1/2	2 1/2	0	0	0	1/2	0	1/2	Low
19	1/2	1	1	1	3 1/2	1/2	0	1/2	1/2	1/2	2	High
20	1/2	1	0	1/2	2	0	0	0	0	1/2	1/2	Low
21	0	1	1	1/2	2 1/2	0	0	0	1/2	0	1/2	Low
22	0	1	0	1	2	0	0	0	0	0	0	Low
23	0	-1	0	1	0	0	0	0	0	0	0	Low
24	0	-1	0	0	-1	0	0	0	0	0	0	Low
25	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
26	0	-1	0	0	-1	0	0	0	0	0	0	Low
27	1/2	-1	0	1	1/2	0	0	0	0	0	0	Low
28	0	-1	0	1	0	0	0	0	0	0	0	Low
29	0	-1	0	1	0	0	0	0	0	0	0	Low
30	0	-1	0	1	0	0	0	0	0	0	0	Low
31	0	-1	0	1	0	0	1/2	0	0	0	1/2	Low
32	0	1	0	1/2	1 1/2	0	0	0	0	0	0	Low
33	0	1	1	1/2	2 1/2	0	0	0	1/2	0	1/2	Low
34	0	-1	1	1/2	1/2	0	0	0	1/2	0	1/2	Low
35	0	-1	1	1/2	1/2	0	0	0	1/2	0	1/2	Low
36	0	-1	0	1	0	0	0	0	0	0	0	Low
37	0	-1	1	1	1	0	0	0	1/2	0	1/2	Low
38	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
39	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
40	0	-1	0	0	-1	0	0	0	0	0	0	Low

Table 34. Recognition criteria for precious-metal deposits in volcanic tuffs--Continued

Map area	Diagnostic: Evidence of precious metals	Diagnostic: Within volcanotectonic subsidence structures	Diagnostic: Presence of nonwelded rhyolitic tuff	Diagnostic: Proximity to high-angle faults	Total	Permissive: Fracturing	Permissive: Anomalous As and (or) Mo	Permissive: Extensive zones of oxidized rock	Permissive: Presence of impermeable barriers	Permissive: Proximity to gold mineralization	Total	Resource potential
41	0	-1	0	1	0	0	0	0	0	0	0	Low
42	0	-1	0	1	0	0	0	0	0	0	0	Low
43	0	-1	0	1	0	0	0	0	0	0	0	Low
44	0	1	1	1	3	0	0	0	1/2	0	1/2	Moderate
45	0	-1	1	1	1	0	0	0	1/2	0	1/2	Low
46	0	1	0	1	2	0	0	0	0	0	0	Low
47	0	1	0	1/2	1 1/2	0	0	0	0	0	0	Low
48	0	1	0	1/2	1 1/2	0	0	0	0	0	0	Low
49	1/2	1	0	1/2	2	0	0	0	0	0	0	Low
50	0	1	0	0	1	0	0	0	0	0	0	Low
51	0	1	0	1	2	0	0	0	0	0	0	Low
52	0	1	1	1	3	0	0	0	1/2	0	1/2	Moderate
53	0	-1	0	1	0	0	0	0	0	0	0	Low
54	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
55	0	-1	1	1	1	0	0	0	1/2	0	1/2	Low
56	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
57	0	-1	1	1	1	0	0	0	1/2	0	1/2	Low
58	1/2	-1	1	1	1 1/2	0	0	0	1/2	0	1/2	Low
59	0	-1	0	1	0	0	0	0	0	0	0	Low
60	0	-1	1	1	1	0	0	0	1/2	0	1/2	Low
61	0	-1	0	1	0	0	0	0	0	0	0	Low
62	0	-1	0	1	0	0	0	0	0	0	0	Low
63	0	-1	1	1	1	0	0	0	1/2	0	1/2	Low
64	0	-1	0	1	0	0	0	0	0	0	0	Low
65	0	-1	1	1	1	0	0	0	1/2	0	1/2	Low
66	0	-1	0	1	0	0	0	0	0	0	0	Low
67	0	1	1	1	3	0	0	0	1/2	0	1/2	Moderate
68	0	1	1	1	3	0	0	0	1/2	0	1/2	Moderate
69	0	1	1	1/2	2 1/2	0	0	0	1/2	0	1/2	Low
70	0	1	0	1/2	1 1/2	0	0	0	0	0	0	Low
71	0	1	1	1/2	2 1/2	0	0	0	1/2	0	1/2	Low
72	1/2	1	1	1/2	3	0	0	0	1/2	0	1/2	Moderate
73	0	1	1	1/2	2 1/2	0	0	0	1/2	0	1/2	Low
74	0	1	1	0	2	0	0	0	1/2	0	1/2	Low
75	0	1	0	0	1	0	0	0	0	0	0	Low
76	0	-1	0	0	-1	0	0	0	0	0	0	Low
77	0	1	0	1/2	1 1/2	0	0	0	0	0	0	Low
78	0	1	0	1/2	1 1/2	0	0	0	0	0	0	Low
79	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
80	0	-1	1	1/2	1/2	0	0	0	1/2	0	1/2	Low

Table 34. Recognition criteria for precious-metal deposits in volcanic tuffs--Continued

Map area	Diagnostic: Evidence of precious metals	Diagnostic: Within volcanotectonic subsidence structures	Diagnostic: Presence of nonwelded rhyolitic tuff	Diagnostic: Proximity to high-angle faults	Diagnostic: Total	Permissive: Fracturing	Permissive: Anomalous As and (or) Mo	Permissive: Extensive zones of oxidized rock	Permissive: Presence of impermeable barriers	Permissive: Proximity to gold mineralization	Permissive: Total	Resource potential
81	0	1	1	1/2	2 1/2	0	0	0	1/2	0	1/2	Low
82	1	1	1	1	4	0	0	0	1/2	1/2	1	High
83	0	1	0	1/2	1 1/2	0	0	0	0	0	0	Low
84	0	1	0	1/2	1 1/2	0	0	0	0	0	0	Low
85	1	1	0	1	3	1/2	1/2	1/2	0	1	2 1/2	Moderate
86	1/2	1	1	1/2	3	0	0	0	1/2	0	1/2	Moderate
87	0	1	0	1/2	1 1/2	0	0	0	0	0	0	Low
88	0	1	0	0	1	0	0	0	0	0	0	Low
89	1/2	1	1	1	3 1/2	1/2	0	1/2	1/2	1/2	2	High
90	0	1	0	1	2	0	0	0	0	0	0	Low
91	0	1	1	1/2	2 1/2	0	0	1/2	1/2	0	1	Low
92	0	-1	1	1	1	0	0	1/2	1/2	0	1	Low
93	0	-1	1	0	0	0	0	0	1/2	0	1/2	Low
94	0	-1	0	0	-1	0	0	0	0	0	0	Low
95	0	-1	1	1/2	1/2	0	0	0	1/2	0	1/2	Low
96	0	-1	1	1/2	1/2	0	0	0	1/2	0	1/2	Low
97	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
98	1/2	-1	1	1/2	1	0	0	0	1/2	0	1/2	Low
99	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
100	1/2	-1	1	1/2	1	0	1/2	0	1/2	0	1	Low
101	0	-1	1	1	1	0	0	0	1/2	0	1/2	Low
102	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
103	0	-1	1	1/2	1/2	0	0	0	1/2	0	1/2	Low
104	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
105	1/2	-1	1	0	1/2	0	0	0	1/2	0	1/2	Low
106	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
107	0	-1	0	1	0	0	0	0	0	0	0	Low
108	0	-1	1	1	1	0	0	0	1/2	0	1/2	Low
109	0	-1	0	1/2	- 1/2	0	0	0	0	0	0	Low
110	1/2	-1	1	1/2	1	0	0	1/2	1/2	1/2	1 1/2	Low
111	0	-1	1	1	1	0	0	0	1/2	0	1/2	Low

pendants within it have produced small amounts of fluorite (Anderson, 1954b; Fisher and others, this volume, p. 140).

Although extensive exploration work has delineated very large resources of fluorspar as breccia-filling deposits in the Bayhorse-Garden Creek area, no production from them has been recorded. Some lead, copper, and silver have been produced from base- and precious-metal deposits that are spatially associated with the fluorite, but are probably of a separate metallogenic event.

At the extensively explored Pacific mine area, where major fluorspar resources have been delineated (Snyder, 1978), stratiform deposits of fluorspar occur at three major horizons in the upper part of the Bayhorse Dolomite and within a few hundred feet of the erosional disconformity that marks the top of the unit. The lowest of these breccia zones, about 280 ft below the top of the dolomite, comprises coarsely crystalline fluorspar that fills the interstices of brecciated, silicified limestone and pisolitic dolomite. A shale-mudstone layer that underlies this breccia-filling zone is locally decomposed and disaggregated and contains very fine grained fluorite that in places assays between 40 and 72 percent CaF_2 (Snyder, 1978). A second zone, approximately 230 ft below the Ramshorn Slate, comprises a major horizon of brecciated and decomposed dolomite that is the host for over 3.2 million tons of 36 percent CaF_2 (Snyder, 1978). The third of these mineralized horizons occurs in the dolomite immediately below the Ramshorn contact, and is best developed on Keystone Mountain about two and one-half miles to the north of the Pacific Mine area and also at numerous other places along this same contact farther to the north. This zone comprises an extensively developed collapse breccia that is the locus for widespread fluorspar deposition and local small amounts of galena and tetrahedrite.

Most of the stratiform zones of brecciated dolomite and silty dolomite that have localized the fluorspar also contain lead, zinc, copper, and silver that range in amounts from a small fraction of a percent to minable ore bodies. One such ore body at the Pacific mine lies immediately above the fluorspar zone and appears to be the product of an earlier and distinctly separate event from the deposition of the fluorspar.

The breccia zones that generally parallel the disconformable contact between the Ramshorn Slate and the Bayhorse Dolomite roughly follow bedding within the dolomite and closely conform to the contact. Their origin is undoubtedly complex. Most probably the process was initiated by the production of collapse breccias related to a karst topography developed on the old pre-Ramshorn Slate erosion surface. These breccia zones were undoubtedly modified and perhaps amplified by subsequent folding and faulting. Migration of aqueous fluids through the porous breccia zones must have further enlarged and modified these zones that became the locale for deposition of both gangue and ore minerals. Tertiary intrusive rocks may have been the source of fluorine and heat for circulation of fluids into sites of deposition.

Descriptive Model

Ore Body

Size and shape: Generally tabular deposits that range in thickness from less than 1 ft to 15 or 20 ft and in the planar dimension from a few tens of feet to $n \times 10^3$ feet. On Keystone Mountain scattered outcrops of a mineralized breccia zone, mostly with covered intervals between exposures, can be traced for nearly 1 mi on the surface across a high ridge on which the vertical distance from the lowest exposed breccia to the highest is over 1,000 ft. At the Pacific mine, a gently sloping tabular ore body measures approximately 1,500 ft by 3,000 ft and ranges from a few feet to over 15 ft thick.

Tonnage and grade: Tonnage of potentially ore-grade material ranges from a few tons at numerous known prospects to over three million tons of proven resources at the Pacific mine that is reported to average 36 percent CaF_2 (Snyder, 1976). The potential exists for similar deposits at other locations along or near the Ramshorn Slate-Bayhorse Dolomite contact. The most favorable area is from Bayhorse Creek northward to and beyond Daugherty Gulch.

Fluorite content of the mineralized breccia zones runs the gamut from a few percent to small pockets or veins of pure CaF_2. Numerous samples from prospects, natural exposures, and mine workings have been analyzed and show a wide range of results that demonstrate the wide extent of mineralization in the Bayhorse Dolomite (Chambers, 1966; Snyder, 1978). Local areas may average from 50 to 60 percent CaF_2, but the extent of most of these higher grade localities is untested. Only the extensively sampled large ore body at the Pacific mine provides a basis for evaluating the future potential of the entire district.

Mineralogy

Ore minerals: Fluorite. Local galena, tetrahedrite, and minor sphalerite generally occur in small amounts in the breccia-filling deposits, and are considered to be contaminants in the fluorspar product.

Gangue minerals: Quartz, chalcedony, sandy dolomite, late calcite, very sparse barite, local sulfide minerals.

In the Pacific mine and at a few other places the Cretaceous sulfide mineralization and the Tertiary fluorite mineralization have been controlled by the same structures and are overlapped, so that the resulting ore body contains a mixed mineralogy.

Commodities

Fluorite

Character of ore

Controlled by stratiform, locally irregularly brecciated horizons in the upper part of the Bayhorse Dolomite. Ore forms tabular deposits at scattered locations within the breccia zones and generally has two modes of occurrence: boxwork fillings and breccia replacement. The boxwork fillings occur only in the breccia zone in the uppermost part of the Bayhorse Dolomite. Brecciated dolomite that was cemented with early silica was subsequently leached of the dolomite. The resulting open silica boxwork provided openings within which the later well-crystallized fluorspar was deposited as partial or complete fillings. The breccia replacement type is characteristic of the breccia zones lower in the dolomite and is represented by the main fluorspar ore body at the Pacific mine. Here the fluorite has replaced finely brecciated sandy dolomite and occurs as finely crystalline white or brownish iron-stained fluorspar whose crumbly nature may be due to minor post-mineral structural adjustment.

Alteration and weathering

Silicification of the dolomite and the overlying Ramshorn Slate along the contact zone by hydrothermal solutions. Surficial leaching of carbonate and oxidation of minor sulfide minerals by meteoric waters. Gossans not notably developed.

Lithology of the host rocks

All known occurrences are within the upper few hundred feet of the Bayhorse Dolomite, but because of the erosional contact, different parts of the dolomite are in contact with the overlying Ramshorn Slate at different places. The carbonate rocks, that are in many places capped by impermeable layers of the Ramshorn Slate, locally contain beds of siltstone or limy siltstone several hundred feet below the top that are spatially associated with mineralized zones as at the Pacific mine.

Controlling structures

All of the known deposits are on the crest and flanks of the Bayhorse anticline. Most mineralization is closely associated with steep throughgoing faults that generally parallel the north-trending axis of the anticline. These major faults, as well as local sets of east-west faults and joints that are more or less perpendicular to the main fold axis, are in many places mineralized with fluorspar and are probably feeding channels for the introduction of ore fluids into the breccia zones. Origin of the breccia horizons and their development as controlling structures for the fluorspar deposits are closely related to a karst topography on an erosion surface cut across the dolomite before deposition of the overlying Ramshorn Slate.

Resource Assessment

From the descriptive model above, we define six recognition criteria of which five are considered to be diagnostic and one permissive.

Diagnostic criteria

1. Presence of carbonate rocks.
2. Breccia horizons at or near a stratigraphic discontinuity at the top of the Bayhorse Dolomite.
3. Steep faults, mostly north trending.
4. Proximity to Tertiary intrusive rocks.
5. Evidence of fluorspar in nearby country rock.

Permissive criteria

1. Base- and precious-metal geochemical anomalies.

Evaluation of the five diagnostic criteria was used to divide the quadrangle into six areas (pl. 17). Each area has been scored and ranked as to its potential--high, moderate, or low--for resources of stratabound, stratiform breccia-controlled fluorspar deposits in carbonate rocks (table 35). Area number 1 on the map was not scored because no carbonate units are mapped within it, and carbonate rocks are mandatory for the localization of these deposits. No deposits of this type could have formed in this area.

Area 4 is the only one that is considered to have high potential for the discovery of new deposits similar to the one at the Pacific mine. It has all of the diagnostic and permissive criteria. Areas 3 and 5 are scored as having moderate potential, but only area 5 is considered to have more than a remote chance for new discoveries because of the favorable diagnostic criteria. Area 3 has only remote possibilities. Areas 2 and 6 have little or no probability for the occurrence of any ore bodies of this type.

Table 35. Recognition criteria for stratabound, stratiform breccia-controlled fluorspar deposits in carbonate rocks (see pl. 17)

Map area	Diagnostic					Total	Permissive	Resource potential
	Presence of carbonate rocks	Breccia horizons in Bayhorse Dolomite	Steep faults	Proximity to Tertiary intrusive rocks	Evidence of fluorspar mineralization		Geochemical anomalies of base or precious metals	
1	(see text)							None
2	1/2	0	0	1/2	0	1	1/2	Low
3	1	0	1	0	1	3	1	Moderate
4	1	1	1	1	1	5	1	High
5	1	1	1	0	1/2	3 1/2	1	Moderate
6	1	0	1/2	0	0	1 1/2	1/2	Low

STRATIFORM BARITE DEPOSITS

By Wayne E. Hall

Stratiform barite deposits are common in siliceous sedimentary rocks of mid-Paleozoic age (Brobst, 1973). Barite beds are a few inches to 50 ft thick and may extend over many acres. They are often interbedded with dark chert and siliceous limestone and shale. Witherite ($BaCO_3$), pyrite, galena, and sphalerite are common accessory minerals. Bedded barite typically contains several percent organic matter and may give off H_2S when broken. Stratiform barite deposits constitute almost 50 percent of the identified barite resource in the United States (Brobst, 1973).

Paleozoic sedimentary rocks host known stratiform barite deposits at three locations in central Idaho. Approximately 13,000 tons of barite was mined from the Sun Valley Barite mine in the Hailey $1^{o}x2^{o}$ quadrangle, 8 mi N. 80 W. of Hailey on Deer Creek. The deposit is described (Umpleby and others, 1930; Kiilsgaard, 1950) as a series of lenticular masses enclosed in rocks that are now mapped as Dollarhide Formation. North of Carey, in the Idaho Falls $1^{o}x2^{o}$ quadrangle, the Muldoon Barite mine is hosted in limestone lenses in calcareous quartzitic beds of Mississippian Copper Basin Formation (Nelson and Ross, 1969). Barite lenses are roughly accordant with bedding and the principal ore body can be followed for 200 ft underground.

In the Challis quadrangle at the Hoodoo mine (pl. 1) a small open cut exposes a bedded barite deposit that is under a subsidiary thrust fault in the Paleozoic Salmon River assemblage below the major thrust fault contact with the overlying Grand Prize Formation. The top of the bedded deposit was sheared off to form a sheared tongue of barite that extends about 100 ft east along the subsidiary fault. The open cut was driven on this sheared tongue. The sheared barite contains disseminated pyrite, sphalerite, and graphite. The west end of the open cut exposes steeply west-dipping stratiform barite that has not been developed along strike. Barite float suggests the deposit extends beyond the unnamed creek on the south.

Use of stream-sediment geochemistry as a guide to possible stratiform barite deposits is complicated by the fact that in the Challis quadrangle barite also occurs as gangue in base- and precious-metal deposits, especially in the carbonate terrane. The regional geochemistry map of barium in panned concentrate samples from the Challis quadrangle (K.M. Johnson, written commun., 1984) indicates that barium is present in anomalous concentrations (>3,000 ppm) in the southeastern part of the quadrangle, predominantly over carbonate terrane and Challis Volcanic Group. Anomalous concentrations of barium are along Squaw Creek, Kinnikinic Creek, and Bayhorse Creek (fig. 3). No study of the mineralogy of the samples has been made to indicate how the barium occurs. It may come from barite gangue in base- and precious-metal deposits (Hobbs and others, this volume, p. 175).

Within the Challis quadrangle, the most likely host rocks for stratiform barite deposits are those included in the black shale terrane. Rock geochemistry indicates the Salmon River assemblage has the highest concentrations of barium of all the black shale formations (fig. 6; Fisher and May, 1983; Simons, 1981). The Salmon River assemblage contains 100 to >5,000 ppm barium, and 9 percent of the samples contain >3,000 ppm (Fisher and May, 1983). The most continuous anomalous samples were collected in Mill Creek (fig. 4).

Although not enough is known to predict any more closely the locations of undiscovered stratiform barite deposits, it is likely that others similar to the Hoodoo mine deposit may be present within the black shale terrane. The number and size of these hypothetical deposits is not known.

STRATIFORM REPLACEMENTS OF URANIUM IN SEDIMENTARY ROCKS

By Kathleen M. Johnson and Theresa M. Cookro

Uranium deposits occur in Tertiary sediments in the Basin Creek area, northeast of Stanley, and on the northeast side of the Pahsimeroi Valley, south of Ellis. The uranium occurs in channel-filling deposits of carbonaceous arkose and mudstone. Production from the Coal Creek #1 and #4, Deer Strike-Elk, East Basin, and Shorty deposits (pl. 18), near Stanley, totalled 6,978 tons of ore at 0.187 percent U_3O_8 between 1958 and 1960 (Choate, 1962). Minor production and exploration activity continued through 1962 and was resumed briefly in the late 1970s (Wopat and others, 1980).

Descriptive model

Ore Body

- Size: nx10^2 ft long; nx10 ft wide; nx10 ft thick
- Shape: lenticular to irregular
- Tonnage and grade: nx10^3 tons of ore ranging at 0.X percent U_3O_8

Mineralogy

- Ore minerals: Uraninite, coffinite, autunite
- Accessory minerals: Pyrite, marcasite
- Matrix: Quartz, feldspars, chlorite, sericite, muscovite, biotite, clay minerals

Commodities

Uranium

Character of ore

Ore minerals are closely associated with carbonaceous material in sandstone, shale, and claystone.

Lithology of host rocks

Interbedded claystones, siltstones, and arkosic sandstones with abundant carbonaceous material including fine-grained "trash" that fills voids and pores; scattered vitrainized wood fragments; thin concordant vitrain seams in mudstone beds; and intercalated beds and lenses of lignite, subbituminous coal, and vitrain (Choate, 1962, p. 32).

Geochemical and mineral indicators

- Geochemical: U, As, Fe, Sb
- Mineral: Pyrite, minor marcasite
- Other: High concentrations of carbon trash are often associated with high uranium values. Areas rich in uranium can be detected with hand-held scintillometers.

Controlling structures and other features

1. In the deposits near Stanley, uranium occurs in paleostream channels that followed pre-existing faults in the underlying rocks of the Cretaceous Idaho batholith.
2. Choate (1962) reports that some of the deposits at Basin Creek were elongated by continuing fault motion; others were offset so far as to be completely detached and to justify continued exploration.

Resource Assessment

From the descriptive model above, we define six recognition criteria, of which we consider four to be diagnostic and two permissive.

Diagnostic criteria

1. Presence of sediments of Tertiary age deposited in fluvial environments, e.g. streams, flood plains, ponds, small lakes, swamps.
2. Evidence of uranium mineralization, including known mines and prospects and presence of uranium in stream sediments.
3. Proximity to high-angle structures.
4. Abundance of carbonaceous material in host rocks.

Permissive criteria

1. Anomalous concentrations of As, Fe, and Sb.
2. High permeability.

We plotted these criteria on the quadrangle map and divided the map into 11 types of areas based on the presence or absence of each criterion (pl. 18). We then scored the areas and ranked each for the likelihood that it contains more deposits analogous to the descriptive model (table 36).

Most of the areas outlined on plate 18 are those in which appropriate Tertiary sediments are shown on the geologic map (Fisher and others, in press). We are unable to estimate the likelihood of appropriate sediments occurring below the surface in areas covered by younger rocks; we do recognize that there is some potential for blind deposits in this situation. Area 6 is an example of this problem. In this area, uranium deposits are known to exist in sedimentary rocks whose outcrop is so limited that they are not shown on the map. Situations like this could exist in any other part of the quadrangle that is covered by younger sedimentary or extrusive volcanic rocks.

Our interpretation of the resource potential is as follows:

Moderate potential: areas 6, 9

Low potential: areas 1-5, 7, 8, 10

We conclude that areas 6 and 9 have moderate potential for more deposits of the type described above. Our optimism is limited because of the extensive exploration that was done in the late 1950s and late 1970s. Those areas listed as having low potential contain some of the diagnostic criteria, but not enough to suggest the likelihood of more deposits. Area 11 has low potential for deposits of this type because of lack of mapped Tertiary sedimentary rocks.

STRATIFORM VANADIUM DEPOSITS

By Wayne E. Hall

Fisher and May (1983) made a study of the Salmon River assemblage in order to evaluate it as a possible vanadium resource. Their results are given in the frequency-distribution plots of 257 random chip samples taken from 20-ft stratigraphic intervals (Fisher and May, 1983; fig. 18). This sampling was done in the vicinity of the Salmon River between Thompson Creek and Slate Creek (fig. 4). They found 26 percent of the samples contained anomalous vanadium (>1,000 ppm) and that most samples enriched in vanadium were also enriched in molybdenum, silver, and zinc. This was a reconnaissance geochemical study and no work has been done to trace along strike the highly anomalous vanadiferous beds containing 0.5 to greater than 1 percent vanadium. The regional geochemistry map of vanadium in stream sediment and rock samples in the black shale terrane (Tschanz and others, 1974) indicates

Table 36. Recognition criteria for stratiform replacements of uranium in sedimentary rocks (see pl. 18)

Map area	Diagnostic criteria: Presence of Tertiary sediments	Evidence of uranium mineralization	Proximity to high-angle structures	Abundance of carbonaceous material	Total	Permissive criteria: Geochemical anomalies	High permeability	Total	Resource potential
1	1	-1	1	1	2	0	1	1	Low
2	1	0	1	-1	1	0	0	0	Low
3	1	0	1	-1	1	1	0	1	Low
4	1	-1	1/2	1	1 1/2	-1	0	-1	Low
5	1	-1	1/2	-1	- 1/2	-1	0	-1	Low
6	1/2	1	1	0	2 1/2	-1	1	0	Moderate
7	1	-1	1/2	-1	- 1/2	1	0	1	Low
8	1	-1	1/2	1	1 1/2	1	0	1	Low
9	1	1	1	1	4	1	1	2	Moderate
10	1	1	1	-1	2	1/2	0	1/2	Low
11	(see text)								Low

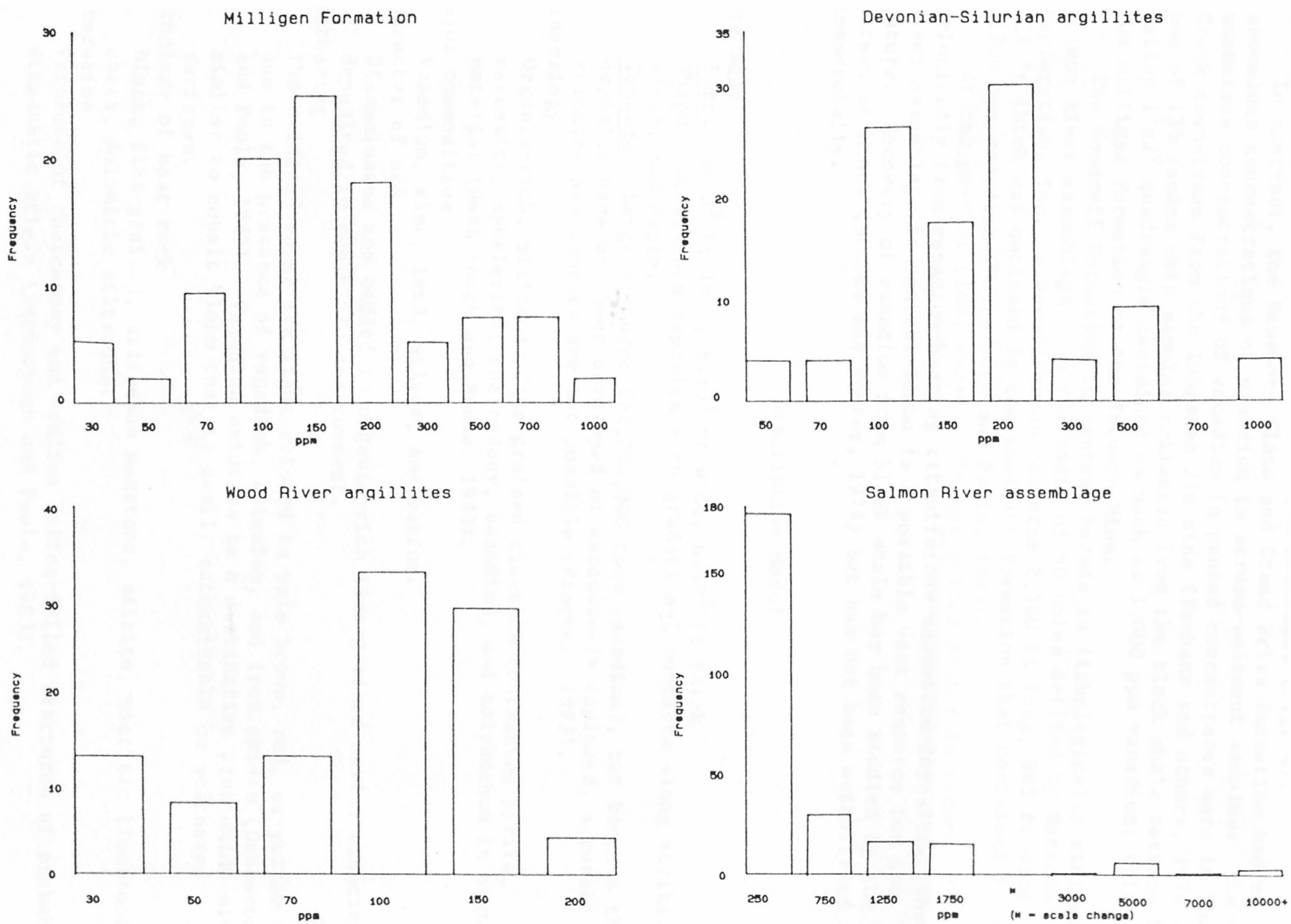

Figure 18. Histograms showing vanadium concentrations in Milligen Formation, undivided Devonian-Silurian argillites, Wood River argillites, and Salmon River assemblage in central Idaho.

vanadium is in anomalous concentrations in the same N. 10° E. belt as zinc, that is, in a belt extending from Washington Basin to Squaw Creek and including the Slate Creek and Mill Creek drainages (fig. 4).

In contrast, the Ramshorn Slate and Grand Prize Formation had no anomalous concentrations of vanadium in stream-sediment samples. The only anomalous concentrations of vanadium in panned concentrates were in Thompson Creek downstream from the Tungsten Jim mine (Tschanz and others, 1974). Only one of 135 random chip samples collected from the black shale terrane in the Hailey 1°x2° quadrangle contained as much as 1,000 ppm vanadium; this was from the Milligen Formation at the Triumph Mine.

The Woodruff Formation in central Nevada is lithologically similar to the Salmon River assemblage. On the basis of 50 holes drilled by Noranda Exploration, Inc., a vanadiferous resource 2,300 ft long, 985 ft wide, and 328 ft thick was outlined in the Woodruff Formation that contained 1,500 to 3,700 ppm vanadium (Desborough and Poole, 1983).

At the present time, vanadium in the United States is recovered principally from vanadium-bearing titaniferous magnetite deposits. The Salmon River assemblage in central Idaho is a possible vast resource for the future. Recovery of vanadium from black shale has been studied by the U.S. Bureau of Mines (Brooks and Potter, 1974) but has not been established commercially.

Descriptive Model

Ore Body

Size: $nx10^3$ ft long; $nx10^3$ ft wide; $nx10^2$ ft thick

Shape: Stratiform deposits with gradational contacts along strike, width, and depth.

Tonnage: Large resource (>1,000,000 tons vanadium), but because these deposits have not been developed or extensively explored, accurate resource assessments are not possible (Fischer, 1973).

Mineralogy

Organic-rich, siliceous fine-grained clastics containing pyrite, marcasite, sphalerite, chalcedony, vanadium, and molybdenum in organic material (Desborough and Poole, 1983).

Major commodities

Vanadium, zinc, lead, silver, and barium.

Character of ore

Disseminated and bedded in organic-rich fine-grained marine clastics deposited in euxinitic environment.

Weathering

The oxidized rocks are light colored in pale brown, red, or yellow tints due to the presence of vanadium, selenium, and iron oxides (Desborough and Poole, 1983). Vanadium oxidizes to a distinctive pink oxide mineral similar to cobalt bloom that is easily recognizable on weathered surfaces.

Lithology of host rock

Black, fine-grained, siliceous mudstone, siltite, micritic limestone, chert, dolomitic siltstone.

Alteration

Veinlets of chalcedony and opaline silica-filled fractures of probable diagenetic origin (Desborough and Poole, 1983).

Geochemical and mineral indicators

Geochemical: Zn, Mo, Ni, Cr, and especially Se and As.

Mineral: Chalcedonic quartz, pink vanadium bloom.

Controlling structures

Vanadium is concentrated, along with zinc, barium, and molybdenum, in the Salmon River assemblage in the postulated synsedimentary downdropped graben structure that extends from Washington Basin N. 10° E. for 24 mi to Squaw Creek (fig. 4).

Resource Assessment

From the descriptive model presented above, three diagnostic and seven permissive recognition criteria are defined:

Diagnostic criteria

1. In black shale terrane.
2. Anomalous concentrations of V in rock or stream-sediment samples.
3. Evidence of synsedimentary tectonics that could localize metalliferous hydrothermal brines--downdropped blocks and (or) deep-seated faults.

Permissive criteria

1. In Salmon River assemblage.
2. Pink vanadium bloom in outcrop.
3. Zn anomalies in rock, pan, or stream-sediment samples.
4. Mo anomalies in rock, pan, or stream-sediment samples.
5. Pb anomalies in rock, pan, or stream-sediment samples.
6. Ba anomalies in rock, pan, or stream-sediment samples.
7. Oxidized strata bleached to much lighter shades of gray and brown.

The quadrangle was divided into 11 areas (pl. 19) that range from areas of little potential to areas of high potential for stratiform vanadium deposits. Each area was evaluated and given semiquantitative evaluation scores for each of the diagnostic and permissive criteria. The basis for the score is described by Fisher (this volume, p. 114). The scores are tabulated in table 37.

Our interpretation of the resource potential for large, low-grade vanadium resources indicated by these semiquantitative scores is:

High potential: area 1

Moderate potential: areas 2, 3, 4, 5, and 6

Low potential: areas 7, 8, 9, and 10

The potential of the Salmon River assemblage for stratiform vanadium deposits was studied by Fisher and May (1983), and they found anomalous concentrations of as much as 1 percent vanadium and that 26 percent of their samples contained anomalous vanadium. The highest concentrations of vanadium are found along the Slate Creek lineament (fig. 4); this lineament also contains anomalous concentrations of zinc, lead, barium, and molybdenum, which are common geochemical associates of vanadium in the black shale environment. We consider that the potential for discovery of a multimillion ton resource containing greater than 0.5 percent V_2O_5 is very high along the Slate Creek lineament.

The areas classified as of moderate potential, areas 2 through 6, are in black shale terrane but contain no widespread concentrations of anomalous vanadium. Area 11 has no potential for stratiform vanadium deposits because the diagnostic host rocks are absent.

Table 37. Recognition criteria for stratiform vanadium deposits (see pl. 19)

	Diagnostic				Permissive								
Map area	Black shale terrane	Anomalous V	Synsedimentary tectonics	Total	Salmon River assemblage	Pink V bloom	Zn anomalies	Mo anomalies	Pb anomalies	Ba anomalies	Bleached, oxidized strata	Total	Resource potential
1	1	1	1	3	1	1	1	1	1	1	1/2	5 1/2	High
2	1	1/2	0	1 1/2	1	0	1/2	1	1/2	0	0	3	Moderate
3	1	1/2	0	1 1/2	1	0	1/2	1/2	-1	1	0	2	Moderate
4	1	1/2	0	1 1/2	-1	0	0	1/2	0	0	0	- 1/2	Moderate
5	1	1/2	0	1 1/2	-1	0	1	-1	1	1	0	1	Moderate
6	1	0	0	1	-1	0	0	-1	-1	1/2	0	-2 1/2	Moderate
7	0	0	0	0	-1	0	1/2	-1	-1	1	0	-1 1/2	Low
8	0	0	0	0	-1	0	0	0	-1	1/2	0	-1 1/2	Low
9	0	-1	0	-1	-1	0	1/2	1/2	-1	1/2	0	- 1/2	Low
10	0	1/2	0	1/2	-1	0	0	-1	1/2	1/2	0	-1	Low
11	-1	-1	-1	-3	-1	-1	-1	1/2	1/2	0	-1	-3	None

STRATABOUND SYNGENETIC DEPOSITS OF PRECIOUS AND BASE METALS IN ARGILLIC ROCKS AND MICRITIC LIMESTONE

By Wayne E. Hall

The black shale terrane in the south-central part of the Challis quadrangle is a favorable environment for shale-hosted exhalative base- and precious-metal, barite, and vanadium deposits. Desborough and Poole (1983) recently described the geologic environment and the metal concentrations of three western metal-rich upper Paleozoic black shales. The three depositional settings they described that are favorable for organic-rich metalliferous marine strata are: (1) continental-rise and marginal-ocean basins, (2) continental-shelf and foreland basins, and (3) cratonic-platform embayments.

The most favorable formation in the Challis quadrangle is the Paleozoic Salmon River assemblage. It is a distal flysch sequence of highly carbonaceous fine-grained siliceous and calcareous clastics deposited in a continental-shelf and foreland basin setting. Fisher and May (1983) sampled the Salmon River assemblage in the vicinity of Slate Creek and Thompson Creek (fig. 4) and analyzed the assemblage as a potential resource for vanadium. Histograms of selected elements are given in figure 18. Their study showed the following enrichment compared to average black shales of the United States:

Metal	Anomalous level (ppm) (based on average black shales reported by Vine and Tourtelot, 1970)	Percent of samples above anomalous level
Barium	3,000	9
Copper	100	25
Molybdenum	50	11
Silver	5	7
Vanadium	1,000	26
Zinc	200	28

No similar geochemical data are available for the other black shale formations in the Challis quadrangle.

Stratabound zinc deposits are known in the Challis quadrangle at the Hoodoo and Livingston mines. Zinc analyses of regional stream-sediment samples indicate widespread anomalous concentrations of zinc in the Salmon River assemblage in the Slate Creek-Mill Creek area, which encompasses both the Hoodoo and Livingston mines (fig. 4). Many of the stream-sediment samples collected from Mill Creek and Slate Creek and its tributaries for the mineral assessment study of the Sawtooth National Recreation Area contained 2,000 to more than 3,000 ppm zinc (Tschanz and others, 1974, fig. 22). These samples with anomalous zinc trend N. 20° E. from the Hoodoo mine for 8 mi in a belt 3 mi wide (fig. 4). The geochemical samples collected for the Challis quadrangle mineral assessment indicate this belt of anomalous zinc concentrations extends 24 mi N. 10° E. from Washington Basin to Squaw Creek and is about 3 mi wide (fig. 4). This belt probably reflects a graben downdropped during sedimentation or early diagenesis, in which metalliferous geothermal brines were localized.

Host rocks for sphalerite mineralization are black, carbonaceous argillite and gray micritic limestone that are near the upper part of the Salmon River assemblage under the regional thrust fault zone at the base of the Grand Prize Formation. The zinc deposit at the Hoodoo mine is in a limestone facies of the Salmon River assemblage. The Livingston deposit is in carbonaceous, siliceous argillite.

Descriptive Model

Ore Body

Size: The maximum size of possible syngenetic base-metal ore bodies for central Idaho is not known. The potential exists for ore bodies to $nx10^7$ tons. The Hoodoo ore body ranges from a few feet to 38 ft wide, and is 1,725 ft long and at least 825 ft deep.

Shape: Tabular, stratiform ore bodies. Contacts with country rock are sharp.

Tonnage and grade: From $nx10^5$ to $nx10^7$ tons. The grade of ore is mostly less than 12 percent total zinc and lead with zinc greatly predominant over lead.

Samples from the Hoodoo ore body indicate a grade of 11 percent zinc and 0.47 percent lead (Van Noy and others, 1974). The sphalerite contains 0.6 percent cadmium and a little silver. Analyses of bedded ore in central Idaho indicate silver averages 0.8 oz/ton for each percent of lead. Stratiform ore in the Milligen Formation at the Triumph mine ($43^o38'$ N., $114^o16'$ W., Hailey 1^ox2^o quadrangle) in the Wood River district contains 13 percent zinc, 5.9 percent lead, and 6.5 oz/ton silver (Kiilsgaard, 1950). The bedded zinc-rich ore at the Livingston mine is a stratiform deposit, but its size is not known because mining has been concentrated on local remobilized ore at the intersections of large felsic dikes with the Livingston stratiform ore, and the extent of the deposit has not been determined.

Mineralogy

Ore minerals: Sphalerite, galena.

Gangue minerals: Pyrite, pyrrhotite, arsenopyrite, quartz, calcite, clay minerals, tremolite.

Lithology of host rock

Black siliceous-facies carbonaceous argillite and fine- to medium-grained gray limestone or micritic carbonaceous limestone that were deposited in a euxinic environment.

Alteration

The recognizable alteration within the black shale terrane has been produced by contact metamorphism around Cretaceous and Eocene plutonic bodies. Alteration zones extend as much as 2 mi from plutonic contacts. Siliceous clastic rocks are altered to hornfels and limy rocks to marble or tremolite-bearing limestone. Alteration adjacent to the stratiform zinc-lead ore bodies is not distinctive. There is silicification and sericitic alteration adjacent to the Hoodoo sphalerite ore body, but this may be later alteration related to the Cretaceous plutonism.

Geochemical and mineral indicators

Geochemical: Zn, Pb, Ba, Ag.

Mineral: Disseminated pyrite and sphalerite in the black shale or in faults that may represent feeder zones adjacent to or below stratiform ore.

Controlling structures

Depositional environments: (1) epicratonic marine basins or embayments; (2) continental shelf and foreland basins; (3) continental-rise and marginal basins. Ore deposition is in active tectonic environments from metal-bearing geothermal brines that rise to the sea floor along deep-seated fault zones. The brines may be concentrated or confined within synsedimentary downdropped troughs or basins.

Geophysical indicators

Geophysical methods have been employed with some success on similar deposits in Selwyn Basin (Carne and Cathro, 1982). The shallow Anvil Camp deposits respond to magnetic, electromagnetic, and gravity surveys (Brock, 1973). An electromagnetic investigation of the Mill Creek zinc anomaly was made by Frischknecht (in Tschanz and others, 1974). He found several good conductor horizons but concluded that they did not indicate any sulfide bodies unequivocally because sphalerite is not a good conductor and thus cannot be detected electromagnetically from the carbonaceous and pyritic argillite.

Resource Assessment

From the descriptive model presented above, three diagnostic and eight permissive recognition criteria are defined.

Diagnostic criteria

1. In a black shale terrane.
2. Anomalous concentrations of zinc and (or) lead.
3. Evidence of deep-seated fault or synsedimentary tectonics that could localize metalliferous hydrothermal brines.

Permissive criteria

1. Presence of barite occurrences or anomalies.
2. Anomalous concentrations of silver and (or) cadmium.
3. Presence of gossan.
4. Highly carbonaceous argillite or micritic limestone.
5. Disseminated pyrite and sphalerite in argillite, limestone, or in synsedimentary fault zones.
6. Presence of Salmon River assemblage rocks.
7. Marine black shale basinal setting.
8. Presence of base- and precious-metal vein deposits.

The quadrangle was divided into eight areas (pl. 20) that range from areas of little potential to areas of high potential for stratabound zinc-lead-silver deposits. Each area was evaluated and given a semiquantitative evaluation score for each of the diagnostic and permissive criteria (table 38).

Interpretation of the resource potential for stratabound syngenetic zinc-lead-silver deposits indicated by these semiquantitative scores is as follows:

High potential: areas 1 and 5

Moderate potential: areas 2, 3, 4, 6, 7, and 8

Low potential: areas 9 and 10.

Areas 1 and 5 both have productive base- and precious-metal mines for which fluid-inclusion and stable-isotope studies indicate that the lead and sulfur came from shallow crustal sources. It is probable that syngenetic mineralization was the source of the sulfur and metals and that the base- and precious-metal vein deposits may be used as a prospecting guide for nearby stratiform deposits. Area 1 contains two known base- and precious-metal deposits--at the Livingston and the Hoodoo mines--in a north-northeast-trending area with widespread anomalous zinc, lead, and silver. Attention should be directed to Mill Creek, where the stream-sediment samples contain highly anomalous zinc, but no deposits are known. Area 5 contains no known stratiform zinc-lead-silver mineralization, but fluid-inclusion and stable-isotope studies of base- and precious-metal ores of the very productive Bayhorse district indicate that a syngenetic source of sulfur and lead from a shallow crustal source is very likely.

Table 38. Recognition criteria for stratabound syngenetic deposits of precious and base metals in argillic rocks and micritic limestone (see pl. 20)

Map area	Diagnostic: Black shale terrane	Diagnostic: Anomalous Zn or Pb	Diagnostic: Evidence of deep-seated fault or syn-sedimentary tectonics	Total	Permissive: Presence barite or Ba anomaly	Permissive: Anomalous Ag, Cd	Permissive: Gossan	Permissive: Carbonaceous argillite or micritic limestone	Permissive: Disseminated pyrite or sphalerite	Permissive: Salmon River assemblage	Permissive: Marine black shale basinal setting	Permissive: Presence of base metal deposits	Total	Resource potential
1	1	1	1	3	1	1	1	1	1	1	1	1	8	High
2	1	1/2	0	1 1/2	1/2	0	1/2	1	1	1	1	1/2	5 1/2	Moderate
3	1	1/2	0	1 1/2	0	0	1/2	1	1	1	1	-1	3 1/2	Moderate
4	1	1/2	0	1 1/2	0	1/2	0	1	1	0	0	1/2	3	Moderate
5	1	1/2	1/2	2	0	1	1	1	1	0	1	1	6	High
6	1	0	0	1	0	0	0	1	1	0	0	-1	1	Moderate
7	1	1/2	0	1 1/2	0	1/2	0	1	1	0	0	0	2 1/2	Moderate
8	1	0	0	1	1/2	1/2	0	0	0	-1	0	0	0	Moderate
9	0	-1	0	-1	1/2	1/2		0	0	-1	0	0	0	Low
10	0	1/2	0	1/2	1/2	1/2		0	1/2	-1	0	1/2	1	Low
11	-1	1/2	-1	-1 1/2	-1	0	0	-1	-1	-1	-1	-1	-6	None

The areas that are classified as having moderate potential for stratabound syngenetic zinc-lead-silver deposits are in black shale terrane, but no widespread concentrations of zinc, lead, or silver were detected from the regional stream-sediment sampling. However, the pattern of sample sites is erratic and a few areas as large as 5 sq mi were not sampled, so significant anomalies could have been missed. Disseminated pyrite and sphalerite are common in the black argillite and micritic limestone in area 2. The disseminated mineralization may be altered to oxide minerals at the surface, but it is very evident in drill cores.

Area 11 has no potential for deposits of this type as it lies outside the black shale terrane.

STRATABOUND SYNGENETIC COBALT-COPPER DEPOSITS

By Kathleen M. Johnson and Earl H. Bennett, Idaho Geological Survey

Cobalt is present in the northeast corner of the Challis quadrangle in stratabound copper-cobalt deposits in quartzites and siltites of the Middle Proterozoic Yellowjacket Formation. The best-known cobalt deposit is the Blackbird mine, located about 7.5 mi north of the quadrangle boundary ($45^{o}07'$ N., $114^{o}20'$ W.) in the Elk City $1^{o}x2^{o}$ quadrangle. The Blackbird mine is the most readily available source of cobalt in the United States with published reserves of 4 million tons of ore containing 0.6 percent cobalt and 1.2 percent copper (Engineering and Mining Journal, 1980).

Three types of cobalt-copper deposits are known in the Yellowjacket Formation (Nash and Hahn, 1986). At Blackbird, the deposits consist of cobalt and copper, as cobaltite and chalcopyrite, in stratabound lodes. These lodes are usually closely associated with tuffaceous rocks. At Iron Creek, lodes of cobaltiferous pyrite, with variable amounts of chalcopyrite, occur in fine-grained clastic metasediments of the middle unit of the Yellowjacket Formation. Pyrite, of very fine to coarse grain size, is abundant in these deposits and magnetite-rich zones are common. Pyrite and magnetite are reworked and redeposited in zones of soft-sediment deformation. South and east of the Blackbird mine, cobaltite-bearing, tourmaline-cemented breccias are common in the lower unit of the Yellowjacket Formation. The breccias include fragments of carbonate and mafic igneous rocks not known in the immediate area, suggesting explosive emplacement. Formation before lithification is indicated by destruction of sedimentary structures in and around the breccia zones. Although these three deposit types differ, we consider them together because they all occur in the same general part of the Yellowjacket Formation and all were formed during or shortly after sedimentation. At the scale of this assessment all three can be described by the same descriptive model and recognized by the same criteria.

Although the Twin Peaks mine (pl. 1) has some similarities to the Blackbird mine, we do not believe they are analogous deposits. Modreski (1985) demonstrates differences in host rock type, ore mineralogy, and character of ore. For purposes of this assessment, we support Modreski's statement that "the Twin Peaks lead-copper deposit . . . may be largely unrelated to the stratabound Blackbird-type deposits" (p. 209) and did not consider Twin Peaks in constructing the descriptive model and making the assessment.

Exploration and mining activity in the Blackbird district began with recognition of gold deposits in 1893. Cobalt was discovered in 1901 and was mined in 1917-20 (Nash and Hahn, 1986). Cobalt and other base and precious metals have been mined whenever price or need for strategic metals has created a favorable market. The most recent activity in the district was a re-evaluation by Noranda Exploration Inc. from 1978 to 1982. Noranda geologists recognized the stratabound character of the mineralization and the significance of the volcanogenic component of the host rocks (Hughes, 1983; Hahn and Hughes, 1984). This new understanding resulted in delineation of a much larger resource than had been known from earlier work. Subsequent cooperative work by Noranda and U.S. Geological Survey geologists is reported by Nash and Hahn (1986). Our description is summarized from the references listed above, Anderson (1943b), Earhart (1986), Modreski (1985), and work at Blackbird by the second author (Bennett, 1977).

Descriptive Model

Ore body
- Size: Lodes occur as individual lenses nx10 ft thick and nx10^3 ft long. At Blackbird at least 12 lodes occur in an area of 3.5 mi^2.
- Shape: Irregular pods and lenses, commonly separated by barren metasedimentary rock.
- Tonnage and grade: nx10^6 tons; 0.X percent cobalt and X.X percent copper

Mineralogy
- Major ore minerals: Cobaltite and chalcopyrite
- Minor but significant: Pyrrhotite, arsenopyrite, safflorite, linnaeite, native gold, native silver, enargite, sphalerite, and galena
- Gangue: Pyrite, biotite, quartz, garnet, tourmaline, muscovite, chloritoid, apatite, and siderite

Commodities
- Cobalt, copper, and gold.

Character of ore
- Ore occurs as fine to fairly coarse sulfides and sulfarsenides in lenses and stringers, locally with cataclasitc textures along shear zones. Pyrite locally has colloform structure.

Lithology of host rock
- Fine-grained metasedimentary rocks (argillite, siltite, and quartzite), and mafic metatuff. Metasedimentary rocks may have large volcanogenic component. Sedimentary structures are abundant, including graded beds, silt-sand couplets, flute casts, load structures, slumped beds, and sand dikelets or volcanoes.

Alteration
- Silicification and intense chloritization.

Weathering products
- Forms prominent gossans where sulfide- and sulfarsenide-rich rocks crop out.

Geochemical indicators
- Enriched in Fe, As, B, Co, Cu, Au, Ag, and Mn. May be depleted in Ca and Na.

Ore controls
1. Ore commonly occupies disrupted beds. Regional distribution of ore closely follows distribution of mafic tuff.
2. Basinal growth faults appear to have influenced location of lodes by determining basin shape, and thus the locus of deposition of mafic tuffs, and providing pathways for mafic intrusions and eruptions.

Resource Assessment

From the descriptive model above, we define eight recognition criteria, of which we consider four to be diagnostic and four to be permissive.

Diagnostic criteria:

1. Presence of fine-grained metasedimentary rocks
2. Sediments were deposited as deepwater turbidites
3. Evidence of synsedimentary mafic intrusions or eruptions
4. Anomalous concentrations of Fe, Co, and Cu.

Permissive criteria:

1. Evidence of silicification and chloritization
2. Anomalous concentrations of As, B, Au, Ag, or Mn
3. Presence of gossans
4. Presence of basinal growth faults.

The recognition criteria were used to divide the quadrangle into 12 types of areas. Eleven of these were scored and ranked for their potential for undiscovered resources of stratabound syngenetic cobalt-copper deposits. Areas labeled 12 were not scored because they contain no mapped metasedimentary rocks; no deposits of this type are expected in area 12.

We have assigned moderate potential to areas 2 and 3. These areas contain some characteristics associated with these deposits, and area 2 also contains the small deposit at Iron Creek. However, our optimism is tempered by the fact that Noranda did extensive exploration at the time of their work at Blackbird and reported no significant finds in the Challis quadrangle.

All other areas were assigned low potential for stratabound syngenetic cobalt-copper deposits. Of particular concern are the evidence for shallow water deposition in area 1 (Fisher and others, in press), the apparent absence of syngenetic mafic intrusions in Paleozoic metasedimentary rocks, and the lack of appropriate geochemical signatures in most areas.

GOLD PLACER DEPOSITS

By Frederick S. Fisher and Kathleen M. Johnson

Gold and silver are common in placer deposits in the Challis quadrangle. The majority of the deposits mined were small and contained a few hundred to several thousand cubic yards of gravel that yielded a few tens to less than 100 oz of gold. Twenty-nine deposits have produced more than 100 oz; of these, ten have produced more than 1,000 oz and three more than 10,000 oz (table 40). Estimated total gold production from placers is 132,300 oz. This estimate is conservative because much of the early production was not recorded.

Placer deposits were first discovered in the Grimes Pass district in 1862; in the Yankee Fork, Loon Creek, Yellowjacket, and Gravel Range districts in the late 1860's; and in the Thunder Mountain district in 1894. Small-scale placer operations have waxed and waned, following the price of gold, ever since the 1800's. Most of the larger placer deposits were mined prior to 1900, with the exception of the Yankee Fork deposit, which was dredged in the late 1940's and 1950's, and placers on Kelly, Stanley, and Rough Creeks that produced mainly in the 1930's. Many other smaller placers were also mined in the 1930's.

Detrital gold may be deposited at any location in a stream channel where decreases in gradient occur or where the stream flow is slowed for any reason. Most of the placer gold in the Challis quadrangle is in fluvial

Table 39. Recognition criteria for stratabound syngenetic cobalt-copper deposits (see pl. 21)

Map area	Fine-grained metasedimentary rocks	Deepwater turbidites	Synsedimentary mafic rocks	Anomalous Fe, Co, and Cu	Total	Silicification and chloritization	Anomalous As, B, Au, Ag, Mn	Presence of gossans	Presence of basinal growth faults	Total	Resource potential
1	1	-1	0	1	1	1	1/2	1/2	0	2	Low
2	1	0	1/2	1	2 1/2	1	1	1	0	3	Moderate
3	1	1/2	1/2	1/2	2 1/2	1/2	1/2	1/2	0	1 1/2	Moderate
4	1	0	0	0	1	0	1/2	0	0	1/2	Low
5	1	0	0	1/2	1 1/2	0	0	0	0	0	Low
6	1	0	0	0	1	0	0	1/2	0	1/2	Low
7	1	0	0	0	1	0	0	0	0	0	Low
8	1	1/2	0	1/2	2	1/2	1/2	1	0	2	Low
9	1	0	0	1/2	1 1/2	0	1/2	0	0	1/2	Low
10	1	1	0	0	2	1/2	1/2	1/2	1	2 1/2	Low
11	1	1	0	0	2	1/2	1/2	0	0	1	Low
12	(see text)										None

Table 40. Placer deposits with production of more than 100 ounces gold

[Sources of data: Cater and others, 1973; Choate, 1962; Umpleby, 1913a, 1913b; Umpleby and Livingston, 1920; and unpublished records of U.S. Bureau of Mines, Spokane, WA. --, no data]

	Au (oz)	Ag (oz)	Yardage	Pre-1900 (dollars)
Boise County				
Grimes Pass District				
Apple Jack	248.12	65.00	--	--
Golden Age	208.57	56.00	13,650	--
J. S. Placer	253.00	85.00	32,530	--
Noble	111.67	44.00	240	--
Custer County				
Loon Creek District				
Loon Creek	--	--	--	1,000,000
Robinson Bar District				
Centauras	--	--	--	80,000
The Great Centennial	--	--	--	100,000
Stanley and Stanley Basin Districts				
Big Casino Creek	--	--	--	8,000
Buckley Bar	--	--	--	250,000
Hot Stuff (Golden Rule)	100.84	39.00	5,200	--
Joe´s Gulch	1,550.17	679.00	--	70,000
Kelley Creek	1,431.41	617.00	--	87,000
Lucky Strike	147.19	59.00	7,350	--
Stanley Basin	423.18	77.00	--	--
Stanley Creek	2,247.26	1,066.00	--	--
Stanley Five Bars	275.00	172.00	46,000	--
Yankee Fork District				
Horsetail	178.00	908.00	--	--
Jordan Creek (Pilot)	7,639.00	4,887.00	520,000	50,000
Pocket	239.00	148.00	1,199	--
Rough Creek	393.97	60.00	8,445	15,000
Yankee Fork	29,356.00	16,150.00	6,666,886	--
Lemhi County				
Forney District				
Ramey & Kane	962.67	603.00	--	--
Yellowjacket District				
Yellowjacket	161.15	12.00	2,750	--
Valley County				
Deadwood Basin District				
Deadwood Basin Mining Co.	646.27	6.00	--	--
Deadwood	213.91	53.00	--	--
H. G. Catlin	137.97	32.00	--	--
Thunder Mountain District				
Dewey	--	--	--	40,000
Sunnyside	162.93	124.00	2,865	--
Bear Valley				
Bear Valley	120.00	64.00	10,000	--

deposits of Pleistocene age. These deposits are commonly in terraces and perched placers a few feet to several hundred feet above present stream channels. The major placers are downstream from, and relatively close to, known lode precious-metal deposits.

Gold is highly variable in size, ranging from a few millimeters up to over an inch in diameter. For example, Tschanz and others (1974) report that the gold in Rough Creek ranged from 0.4 to 30 mm. In Monumental Creek (Thunder Mountain district) the gold was extremely small, requiring 300-1,000 colors to the ounce (Cater and others, 1973). In Loon Creek, nuggets greater than an inch in diameter were not uncommon; most of the gold was 1/8-1/4 in. in diameter.

Lode deposits of gold are widespread in the Challis quadrangle and many have been deeply eroded during Pleistocene and Holocene time, resulting in an abundance of placer gold deposits. Substantial amounts of placer gold undoubtedly still remain. Much of this gold most likely is within the Yankee Fork, Stanley, and Loon Creek districts. In the Yankee Fork district dredging was notably inefficient (Choate, 1962, p. 106). In places, the dredge could not reach the best pay streaks, which are found just above bedrock. Large areas of alluvium along the Yankee Fork were never dredged, and it is estimated that only 60 percent of the gold that was dredged was actually saved (Choate, 1962, p. 106). The Loon Creek district has never been dredged and dredging in the Stanley district was ineffective because of mechanical difficulties and the high clay content of the alluvium. In many parts of Idaho, particularly Boise Basin, placer ground has been profitably dredged as much as three times. We estimate the total available resource contained in placer deposits to be in excess of 350,000 oz of gold and an unknown amount of silver.

Descriptive Model

Ore Body

Size: Highly variable, from a few tens of acres to several thousand acres. Thickness ranges from a few feet to more than one hundred feet.

Shape: Irregular, generally blanket-like; may be in terraces, valley fill, channel deposits, or as perched gravels.

Yardage and grade: Highly variable from a few hundreds to tens of millions of cubic yards. Grades range from 0.0x to 0.00x oz gold per cubic yard.

Mineralogy

Ore minerals: Free gold and electrum.

Other minerals: Ilmenite, magnetite, euxenite, brannerite, zircon, monazite, cinnabar, stibnite, and garnet.

Commodities

Major commodities produced are gold and silver. Possible byproduct production of radioactive minerals, niobium, tantalum, and rare earth elements from associated black sands.

Character of ore

Size of gold ranges from a few millimeters to over an inch in diameter. Fineness ranges from 590 to 930. Most districts had an average reported fineness of about 760.

Lithology of host rock

Alluvium, principally Pleistocene in age, consisting of sand, gravel, and boulders. Most clasts are less than 2 ft in diameter. Some deposits have considerable clay.

Geochemical and mineral indicators

Sediments from streams that are eroding gold placers may be enriched in gold and silver (McDanal and others, 1984). Black sand minerals are abundant.

Ore controls

Detrital gold is deposited where stream gradient or flow are reduced, usually within a few miles of the source lode.

Geophysical indicators

Seismic surveys may be useful in defining gravel depths for large deposits.

Resource Assessment

From the descriptive model above, we define six recognition criteria, of which three are diagnostic and three permissive.

Diagnostic criteria

1. Evidence of precious metal mineralization. This may be either geochemical anomalies, lode mines or prospects, or placer deposits.
2. Within 5 mi downstream of known precious-metal lode deposits.
3. Presence of adequate alluvium. At our map scale (1:250,000) many areas of alluvium large enough to contain productive placers were too small to be shown, but our assessment was based on both mapped and unmapped alluvium.

Permissive criteria

1. Alluvium of Pleistocene age.
2. Source streams eroding known gold deposits.
3. Evidence of placer potential based on testing of known or suspected deposits. Testing methods included test pitting and trenching of small placers, channel sampling, churn drilling, and backhoeing. Results of these tests are reported in Cater and others (1973), Kiilsgaard and others (1970), Tschanz and others (1974), and Choate (1962).

Based on these criteria, 57 areas were delineated within the Challis quadrangle (pl. 22) and each area was ranked by scoring the individual diagnostic and permissive criteria. The scores are tabulated in table 41. Six areas (7, 21, 30, 42, 43, and 56) were assigned a high resource potential; nine areas (6, 9, 11, 14, 19, 23, 25, 38, and 52) were assigned a moderate potential; and the remaining 42 areas were assigned a low potential. In all of the areas the indicated potential exists only within alluvial deposits.

In areas of high potential, we believe that there is a high probability that one or more undeveloped precious-metal placers exists. We believe that in each area one of these placers will contain at least 10,000 oz of gold and any other deposits will contain between 100 and 10,000 oz. Assuming an average fineness of 760, there is also a significant resource of silver in these deposits. In area 43, the U.S. Bureau of Mines (Tschanz and others, 1974, p. 631) estimated that placers in Valley Creek contain 10 million cubic yards of gravel with a gold content ranging from a trace to 120 cents per cubic yard and averaging 16.9 cents (at $65.59 per oz of gold), for a calculated total of 25,766 oz of gold. Total conditional resources in area 43 include 30,620 oz of gold. In area 42, total conditional resources equal 6,714 oz, contained in Robinson Bar, Easy Bar, Treon Creek Bar, Cold Creek Bar, and Burnt Bar, all located along the Salmon River (Tschanz and others, 1974, p. 631, table 37). In the Yankee Fork district (area 30), drilling prior to dredging in the 1940's indicated a gold content worth $11 million.

Table 41. Recognition criteria for gold placer deposits (see pl. 22)

Map area	Diagnostic criteria: Evidence of precious metals	Diagnostic criteria: Proximity to lodes	Diagnostic criteria: Presence of adequate alluvium	Total	Permissive criteria: Pleistocene alluvium	Permissive criteria: Source streams eroding lodes	Permissive criteria: Tested resource	Total	Resource potential
1	1/2	-1	1/2	0	1/2	-1	0	- 1/2	Low
2	1/2	1/2	1/2	1 1/2	1/2	1/2	0	1	Low
3	1/2	-1	1/2	0	1	-1	0	0	Low
4	1/2	-1	1/2	0	1	-1	0	0	Low
5	1/2	1/2	1/2	1 1/2	1/2	1/2	0	1	Low
6	1	1	1/2	2 1/2	1/2	1	0	1 1/2	Moderate
7	1	1	1	3	1/2	1	1/2	2	High
8	1	1/2	1/2	2	1/2	1	0	1 1/2	Low
9	1	1	1/2	2 1/2	1/2	1	1/2	2	Moderate
10	1	1/2	1/2	2	1/2	1/2	1/2	1 1/2	Low
11	1	1	1/2	2 1/2	1/2	1	0	1 1/2	Moderate
12	1/2	-1	1	1/2	1/2	-1	1/2	0	Low
13	1/2	-1	1/2	0	0	-1	0	-1	Low
14	1	1	1/2	2 1/2	1/2	1	0	1 1/2	Moderate
15	1/2	-1	1/2	0	1/2	-1	0	- 1/2	Low
16	1/2	-1	1/2	0	0	-1	0	-1	Low
17	1/2	-1	1/2	0	0	-1	0	-1	Low
18	1/2	1	1/2	2	1/2	1	0	1 1/2	Low
19	1	1/2	1	2 1/2	1/2	1	1/2	2	Moderate
20	1/2	1	1/2	2	1/2	1/2	0	1	Low
21	1	1	1	3	1	1	1	3	High
22	1/2	1	1/2	2	1/2	1/2	1/2	1 1/2	Low
23	1	1/2	1	2 1/2	1/2	-1	1/2	0	Moderate
24	1/2	-1	1/2	0	1/2	-1	0	- 1/2	Low
25	1	1/2	1	2 1/2	1	-1	0	0	Moderate
26	1/2	-1	1/2	0	1/2	-1	0	- 1/2	Low
27	1	-1	1	1	1	-1	0	0	Low
28	1/2	-1	1	1/2	1	-1	0	0	Low
29	1/2	1/2	1/2	1 1/2	1/2	-1	0	- 1/2	Low
30	1	1	1	3	1	1	1	3	High
31	1/2	-1	1/2	0	1/2	-1	0	- 1/2	Low
32	1/2	1	1/2	2	1/2	1	0	1 1/2	Low
33	1/2	-1	1/2	0	0	-1	0	-1	Low
34	1/2	1/2	1/2	1 1/2	0	0	0	0	Low
35	1/2	1/2	1/2	1 1/2	0	0	0	0	Low
36	1/2	1/2	1/2	1 1/2	1/2	1/2	0	1	Low
37	1/2	1/2	1	2	1	1/2	0	1 1/2	Low
38	1	1	1/2	2 1/2	1	0	0	1	Moderate
39	1/2	1/2	1	2	1	1/2	1/2	2	Low
40	1/2	-1	1	1/2	1	-1	1/2	1/2	Low
41	1/2	-1	1	1/2	1	-1	1/2	1/2	Low
42	1	1	1	3	1	1	1/2	2 1/2	High
43	1	1	1	3	1	1	1	3	High
44	0	1/2	1/2	1	1	1/2	0	1 1/2	Low
45	0	1/2	1/2	1	1	1/2	0	1 1/2	Low

Table 41. Recognition criteria for gold placer deposits--Continued

Map area	Diagnostic criteria: Evidence of precious metals	Proximity to lodes	Presence of adequate alluvium	Total	Permissive criteria: Pleistocene alluvium	Source streams eroding lodes	Tested resource	Total	Resource potential
46	1/2	1/2	1/2	1 1/2	1	1/2	1/2	2	Low
47	1/2	-1	1/2	0	1/2	-1	1/2	0	Low
48	1/2	-1	1/2	0	1/2	-1	1/2	0	Low
49	1/2	-1	1/2	0	1/2	-1	1/2	0	Low
50	1/2	-1	1/2	0	1/2	-1	1/2	0	Low
51	1/2	-1	1/2	0	1/2	-1	1/2	0	Low
52	1	1/2	1	2 1/2	1/2	1/2	1/2	1 1/2	Moderate
53	1/2	-1	1/2	0	1/2	-1	0	- 1/2	Low
54	1/2	1/2	1/2	1 1/2	1/2	1/2	0	1	Low
55	1	1/2	1/2	2	1	1/2	0	1 1/2	Low
56	1	1	1	3	1	1	1/2	2 1/2	High
57	1/2	1/2	1/2	1 1/2	1/2	1/2	0	1	Low
58	(see text)								Low

At $35 per oz, that equals 314,286 oz of gold. Of that total, approximately 30,000 oz has been recovered by dredging and placer mining, leaving a large resource. In area 21, the U.S. Bureau of Mines estimated that the Loon Creek area contains 1,611,000 cubic yards of gravel with an average grade of 0.0035 oz of gold per cubic yard (Ridenour, written commun., 1985).

In each area ranked as having moderate potential, we believe that there is a 50 percent chance that a placer deposit containing 100 oz of gold exists. Some of these areas have had minor placer production in the past; others have been tested and shown to have small amounts of gold in the gravels (Cater and others, 1973; Kiilsgaard and others, 1970; Tschanz and others, 1974). However, the evaluation of the gold content of placers is difficult and with additional testing new discoveries may be made.

In the remainder of the quadrangle the potential for gold placers is at best low. The probability of a productive placer deposit existing in areas ranked as having low potential with diagnostic criteria present is slight; these areas were delineated because they meet our first diagnostic criterion by showing some evidence of precious-metal mineralization. In the parts of the quadrangle shown as area 58, none of the diagnostic criteria are present. These areas have a low potential for gold placer deposits. More work in these areas could bring to light evidence of the sort we have used to delineate potential, but no such information is known to us at this time.

RADIOACTIVE BLACK-SAND PLACER DEPOSITS

By Thor H. Kiilsgaard and Wayne E. Hall

Extensive radioactive black sand placer deposits occur in many alluviated valleys of the Challis quadrangle. As used here, "black sand" is chiefly ilmenite and magnetite, but it also contains other heavy minerals, some of which are radioactive. Monazite and euxenite are the principal radioactive minerals in the deposits. Other radioactive minerals that have been identified include brannerite, xenotime, and samarskite (Shannon, 1926; Kline and Carlson, 1954; and Kline and others, 1955). At Bear Valley, heavy black minerals that appeared to be members of a series of uranium-bearing rare earth columbates and tantalates were not identified by Schmidt and Mackin (1970) but were referred to collectively as "radioactive blacks." The exact mineralogy of some of these heavy black minerals has never been determined. Other heavy minerals of economic interest include columbite-tantalite, garnet, and zircon. Some of the largest and richest deposits are in the western part of the quadrangle, along the eastern edge of Long Valley. The Long Valley deposits are along westerly-flowing streams that have eroded granitic rocks of the Idaho batholith and some deposits extend beyond the western boundary of the Challis quadrangle (pl. 23).

All of the placer deposits are of alluvial origin and most are of Pleistocene age. They represent the accumulation of valley-fill from transporting streams. The deposits formed where the transporting stream gradient decreased to a level at which the streams could not transport the alluvial load. The decrease in stream gradient resulted from blockage of the streams: commonly either by faulting, as in Long Valley (Mackin and Schmidt, 1956); by Pleistocene glacial ice or moraine damming as in Bear Valley; by landslides; or by the damming action of basalt flows as in Boise Basin. Placers normally are thicker at the downstream end, where blockage originally occurred. Some placers extend to unknown depths. The deepest hole drilled at the Pearsol Creek deposit (pl. 23, table 42) went to 120 ft without meeting bedrock. A nearby water well, drilled west of the deposit, went more than 400 ft in alluvium without reaching bedrock (Kline and Carlson, 1954).

Gravel size in alluvium of radioactive placer deposits is small. Most of the heavy minerals are in lenses and beds of coarse sand and fine gravel, the larger pebbles of which are rarely more than 2 in. in diameter. Beds of fine sand and clay are common in the deposits and normally contain lesser amounts of heavy minerals than coarser sand and gravel. Presently degrading stream beds may contain larger boulders, transported by floods, but boulders are uncommon in deeper parts of the deposits. Larger boulders also are found at the mouths of aggrading tributary streams, whose outwash fans may cover parts of the older alluvial deposit in the main valley.

Radioactive minerals are found throughout most alluvial deposits. Degrading streams that have eroded upper parts of the deposits winnow the lighter minerals away leaving a concentration of the heavier radioactive minerals near the surface. Holes drilled in various deposits, however, show concentrations of radioactive minerals to greater depths. At the Pearsol Creek deposit in Long Valley, monazite values were found to a depth of 120 feet, the deepest hole drilled, although a more consistent content of monazite was found at depths ranging from 15 to 55 feet (Kline and Carlson, 1954). In the central part of Bear Valley, monazite was found in the two deepest holes, BV 20 and BV 21, both of which were drilled to a depth of 100 feet without reaching bedrock (Kline and others, 1953).

Radioactive minerals in the placer deposits originated in granitic rocks of the Idaho batholith. The minerals were disseminated throughout the batholith and were released from their original sites through the processes of weathering, rock decomposition, and erosion. As heavy resistant minerals, they tended to settle in decomposing surficial material, whereas the lighter minerals were more readily removed by erosion. This lag effect in erosional transport formed an enriched mantle on pre-Pleistocene surficial areas of batholithic rock that was available to accelerated periglacial erosion brought on by Pleistocene glaciation. The richest placer deposits are those of early Pleistocene age, formed by erosion and transport of the pre-Pleistocene surficial material. Late Pleistocene and recent deposits usually contain lesser quantities of heavy minerals, although some are enriched locally in heavy minerals through the winnowing action of the transporting stream.

The most common heavy mineral in the black sands of radioactive placer deposits is ilmenite ($FeTiO_3$). This is contrary to what might be expected, as magnetite ($FeFe_2O_4$) is more common in the granitic host rock. Magnetite in low-gradient placer deposits, however, is dissolved by acidic ground water (Schmidt and Mackin, 1970) and is largely removed. Ilmenite content in placers varies widely, ranging from 2 lbs ilmenite per cubic yard of gravel in Horsethief Basin to 16 lbs of ilmenite per cubic yard of gravel in the Pearsol Creek deposit (pl. 23, table 42). Ilmenite from 9 deposits in Long Valley averaged 46.1 percent TiO_2 (Storch and Holt, 1963). Other black-sand minerals in Idaho placer deposits are discussed by Savage (1961).

Monazite, a rare-earth mineral whose principal components are cerium, lanthanum, and neodymium oxides but which also contains thorium and uranium, along with other elements, was the principal mineral mined from the Long Valley placer deposits in the early 1950's. At that time, the market price for monazite concentrates that contained 60 percent combined rare-earth oxides was about $0.18 per pound and a placer had to contain at least 1 pound of monazite per cubic yard of gravel to be considered economically exploitable. Average monazite content of different placers and average ThO_2 and U_3O_8

Table 42. Radioactive black sand placer deposits in the Challis quadrangle that have been explored by drilling

Deposit	Area sq yd	Average depth yd	Volume cu yd	Average mineral content (lbs/cu yd) Ilmenite	Garnet	Zircon	Monazite	Monazite ThO_2 --percent--	U_3O_8	Resources of ThO_2 in monazite, short tons
Deposits that contain 0.50 or more lb monazite per cu yd of alluvium										
Big Creek[1,9]	3,570,000	20	71,400,000	14	2.10	.70	1.50	4.2	.13	2,250
Pearsol Creek[2,9]	6,500,000	20	130,900,000	16	.40	.10	1.60	4.4	--	4,580
Corral Creek[3,9]	6,350,000	19	120,700,000	4	.10	.10	1.80	4.4	.10	4,780
Upper Clear Creek[4]	640,000	5	3,200,000	6	5.00	.20	1.20	4.1	--	80
Lower Clear Creek[4]	5,000,000	16	80,000,000	5	5.00	.10	.70	4.1	--	1,150
Hull's Big Creek[5]	1,100,000	4	4,400,000	2	.60	.30	3.40	4.1[6]	--	310
Scott Valley[7]	7,500,000	13	97,500,000	10	1.90	.70	.80	4.1	.17	1,600
Horsethief Basin[7]	3,000,000	13	39,000,000	2	.30	.30	1.30	4.7	.11	1,190
Little Valley of Gold Fork[4]	10,600,000	10	106,000,000	7	6.00	.50	.50	4.8	--	1,270
Bear Valley (Big Meadows)[8]	4,800,000	14	67,200,000	12	2.80	--	.75	4.6	.27	1,160
Central Bear Valley[9]	13,300,000	12	160,000,000	7	1.40	.06	.60	4.6	.27	2,210
White Hawk Basin[5]	800,000	4	3,200,000	3	5.00	--	.80	4.2[6]		50
Gold Creek-Williams Creek[9]	1,600,000	15	24,000,000	4	--	--	.90	4.2[6]	--	450
									Total:	21,080
Deposits that contain less than 0.50 lb monazite per cu yd of alluvium										
Paddy Flat[5]	2,400,000	16	38,400,000	12	3.0	--	.40	4.2[6]	.18	320
Lower Bear Valley[9,11]	16,400,000	10	164,000,000	4			.10	4.6	--	380
Pigtail Cr. (Meadows)[5]	2,200,000	17	37,400,000	.6	--	--	.10	4.2[6]	--	80
Deadwood Valley[9]	16,400,000	10	164,000,000	4	.4	.10	.10	4.2[6]	--	340
Peace Valley[9]	2,500,000	4	10,000,000	2	--	--	.30	4.2[6]	--	60
Garden Valley[9]	9,000,000	27	243,000,000	2	--	--	.20	4.2[6]	--	1,020
Stolle Meadows[9]	3,900,000	15	58,500,000	2	--	--	.20	4.2[6]	--	250
Kelly Creek[9]	24,000	5	120,000	3			.10	4.2[6]	--	--
Stanley Creek[9]	1,400,000	15	21,000,000	3	--		.20	4.2[6]	--	90
Payette Placer[10]	3,240,000	25	81,000,000	11[11]	4[12]					
									Total:	2,540
									Grand Total:	23,620

[1]Kline and others, 1951a.
[2]Kline and Carlson, 1954.
[3]Kline and others, 1955.
[4]Unpublished U.S. Bureau of Mines data.
[5]Unpublished Defense Minerals Exploration Administration data.
[6]Estimate.
[7]Kline and others, 1951b.
[8]R. D. Porter, written communication, 1985.
[9]Storch and Holt, 1963.
[10]Kiilsgaard and others, 1970.
[11]Black sand, not ilmenite.
[12]Total nonmagnetic fraction.

content of monazite in some of the placers is shown in table 42. Three bucket-line dredges worked on the Big Creek deposit (pl. 23) from 1950 to 1955 and are estimated to have dredged 12,880,000 yd^3 of gravel, from which was recovered 7,085 short tons of monazite that yielded 297 short tons of ThO_2 (Staatz and others, 1980). The three dredges also produced 77,300 short tons of ilmenite, 4,510 short tons of garnet, and 2,580 short tons of zircon. Dredge mining at the Big Creek deposit ceased in 1955 when government contracts for monazite were completed (Eilersten and Lamb, 1956).

Alluvial deposits in three contiguous areas along Bear Valley Creek (pl. 23) contain radioactive and niobium- and tantalum-bearing minerals. Of the three deposits, the one farthest upstream (Big Meadow) is the largest and most enriched in radioactive black minerals. Euxenite is the predominant ore mineral at the Big Meadow deposit, along with lesser quantities of monazite and columbite. Drilling of the deposit in 1951 and 1952, by the U.S. Bureau of Mines (Kline and others, 1953), and subsequent dredging from 1955 to 1959 show that richer concentrations of euxenite occur along the upper eastern side of the deposit, whereas monazite is more concentrated along the western side. Mackin and Schmidt (1956) describe euxenite crystals and grains in upstream parts of Bear Valley and note that size of the grains decreases by 3 to 4 times within the first mile of downstream transport. The grain-size reduction may be attributed to the hard and brittle nature of euxenite and its tendency to break up during alluvial transport. Monazite, on the other hand, is a durable mineral and grains of it are only slightly affected by stream transport.

Euxenite along the eastern side of Big Meadow deposit probably was derived chiefly from Tertiary intrusive rocks that crop out near the head of Cache Creek, a tributary to Bear Valley Creek. Petrographic studies and radiometric counts show that these Tertiary intrusive rocks contain more radioactive minerals than the Cretaceous plutonic rocks they intrude. An alluvial fan near the mouth of Casner Creek contained the highest concentration of euxenite mined from the Big Meadow deposit. Casner Creek heads in an area which is partially covered by Pleistocene glacial moraine, and which contains gravels derived from Tertiary intrusive rock that was scoured from the headwaters area of Cache Creek.

Euxenite, a niobate and tantalate of the yttrium group of rare-earth minerals, also contains varying amounts of uranium. Analyses of the Big Meadow euxenite and columbite, provided by R. P. Porter (Porter Brothers Corporation, written commun., 1985) are:

Euxenite			Columbite		
Nb_2O_5	27.07	percent	Nb_2O_5	60.84	percent
Ta_2O_5	3.01	"	Ta_2O_5	7.64	"
TiO_2	20.91	"	TiO_2	2.09	"
U_3O_8	10.25	"	U_3O_8	1.50	"
ThO_2	2.80	"			
SiO_2	3.24	"			
$RE_2O_3+Y_2O_3$	18.86	"	Re_2O_3	1.89	"
P_2O_5	0.98	"			
MnO_2	1.00	"	MnO_2	7.91	"
MgO	0.44	"			
Fe_2O_3	5.30	"	Fe_2O_3	11.74	"
Al_2O_3	1.07	"			
Unclassified	5.07	"	Unclassified	6.39	"
	100.00			100.00	

According to Porter (written commun., 1985) the rare earth (Re_2O_3+Y_2O_3) fraction of euxenite is composed of the following oxides:

Y_2O_3	57.9 percent	Tb_4O_7	1.3 percent
La_2O_3	2.4 "	Dy_2O_3	7.4 "
CeO_2	5.9 "	Ho_2O_3	1.9 "
Pr_6O_{11}	0.8 "	Er_2O_3	3.3 "
Nd_2O_3	3.8 "	Tm_2O_3	0.9 "
Sm_2O_3	2.2 "	Yb_2O_3	3.2 "
Eu_2O_3	0.1 "	Lu_2O_3	0.4 "
Gd_2O_3	5.9 "		

The Porter Brothers Corporation began dredging the Big Meadow deposit with one bucket-line dredge in 1955 and installed a second bucket-line dredge in 1956 (fig. 19). Dredging capacity of the two dredges was 7,000 to 8,000 yd^3 per day. Approximately 6,500,000 yd^3 of placer alluvium was dredged from the deposit, from which was recovered 2,049 short tons of euxenite, 83.5 short tons of columbite, and 54,862 short tons of ilmenite (Staatz and others, 1980). Records on the amount of monazite recovered are not available. Big Meadow dredge production made Idaho the largest producer of niobium and tantalum in the United States during the late 1950's (Parker, 1964). Dredging ceased in 1959, when Porter Brothers Corp. fulfilled their contract to provide 1,050,000 pounds containing 90 percent niobium-tantalum pentoxides to the U.S. Government General Services Administration stockpile. Porter Brothers Corp. estimates that about 67,000,000 yd^3 of dredgable alluvium remain at Big Meadow, the average grade which is about 0.40 pounds of euxenite and columbite and 0.75 pounds of monazite per cubic yard (R.B. Porter, written commun., 1985).

Most of the deposits listed in table 42 as containing 0.50 or more lbs monazite per cubic yard also contain minor quantities of columbite-tantalite. Chemical analyses show the columbite-tantalite content of the ilmenite fraction of Custer and Valley County deposits (those in the Challis quadrangle) to range from 0.18 to 0.40 percent Nb_2O_5 (Storch and Holt, 1963, table 1). The total resources of niobium and tantalum in Idaho placer deposits are estimated at 20,000 tons of combined pentoxides, making Idaho one of the largest sources in the United States (National Academy of Sciences--National Research Council, 1959, p. 65). Most of these resources are in the Big Meadow deposit of Bear Valley (Parker, 1964).

Dredging has been soundly criticized for impairing the beauty of mountain valleys. Such criticism is warranted at many localities; however, little harm is done to the valley surface if care is taken to remove the soil cover prior to dredging and then to level the piles of dredge tailings, restore the soil cover, and plant grass after dredging is completed. Such restoration action was taken at Big Meadow and parts of the dredged site were difficult to distinguish from natural meadow in 1985 (fig. 20A and B).

Alluvial deposits that have been tested by drilling and are known to contain significant quantities of heavy minerals and ThO_2, and minor amounts of U_3O_8 are listed in table 42. Deposits that contain 0.5 lb or more monazite per cubic yard are shown separately as they would be the more likely candidates for exploitation, should economic conditions make dredging feasible. Volume estimates for the deposits are considered conservative as overall depths of most deposits probably exceed averages shown in the table. Deposits containing an average of less than 0.5 lb monazite per cubic yard would be dredgable only in case of a very high price for thorium. Present dredge laws and pollution restrictions in Idaho make bucket-line dredging unlikely.

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Figure 19. Porter Brothers Corp. bucket-line dredges operating in the Big Meadow deposit in the late 1950s.

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Figure 20. Restoration at Big Meadow. A. Bulldozer at Big Meadow deposit, leveling the dredge tailings in the late 1950's in preparation for restoration of original soil cover, which had been stripped from the dredged area and stacked at the side prior to dredging. B. View of Big Meadow in 1985. Only traces of dredging remain on the meadow surface.

The following model is based on the foregoing information; it represents an attempt to summarize pertinent characteristics of radioactive placer deposits.

Descriptive Model

Ore Body

Size: May range from hundreds of feet to a mile or more in width, be several miles in length, and range from a few feet to more than 100 feet in thickness.

Shape: A flat, alluvial blanket that conforms more or less to the shape of the valley floor but which varies considerably in thickness.

Yardage and grade: To be economically exploitable, a deposit should be large enough to support a dredging operation for several years. It should contain at least $nx10^6$ yd^3 and a minimum of 0.5 lb monazite or other radioactive minerals per yd^3.

Mineralogy

Ore minerals: Monazite, euxinite-polycrase, brannerite, samarskite, xenotime, fergusonite, uranophane, columbite, allanite, ilmenite, magnetite, zircon, garnet, and gold.

Major commodities

Listed in decreasing order of importance: ThO_2, rare-earth oxides, niobium and tantalum pentoxides, U_3O_8, ilmenite, zircon, garnet, gold.

Character of ore

Heavy minerals of the black sand group of minerals, some of which are referred to as radioactive blacks. Individual black-sand grains are chiefly minus 16-mesh in size and may be present in amounts ranging from less than 1 lb/yd^3 to more than 30 lbs/yd^3 of alluvium. Ilmenite is the chief black-sand mineral; present in lesser amounts are magnetite, radioactive minerals, and other heavy minerals. Because the minerals are present as individual crystals or grains they may be readily separated and concentrated by various gravity or electromagnetic-electrostatic methods.

Lithology of the deposit

Alluvium, principally of Pleistocene age and consisting chiefly of sand and pebbles of granitic rock. Deposits are in areas of low stream gradient and contain few boulders, although surface and near-surface areas may consist of Holocene (Recent) alluvium containing more boulders transported by high-energy streams. Also, older alluvial deposits may be overlain in part or completely by late Pleistocene glacial moraine.

Controlling structures and other features

An impediment or blockage of stream flow that has reduced stream gradient and allowed deposition of the heavy minerals being transported by stream action. Heavy minerals at some deposits have been further concentrated by the winnowing action of flowing water that has removed light minerals and left heavier ones behind.

Mineral indicators

The principal indicator in a stream bed is black sand, which may be concentrated by panning the alluvium. Magnetite may be identified with a magnet and red garnet by visual inspection. Radioactive minerals may be identified with a geiger counter or a gamma-ray spectrometer. Some heavy minerals require microscopic study or X-ray analysis for identification.

Geophysical indicators

Gravity surveys give information on the overall depth of alluvial deposits and seismic refraction surveys define the depth to bedrock beneath a deposit more exactly. A proton precision magnetometer survey may aid in delineating the course of enriched paleochannels within the alluvium.

Resource Assessment

The radioactive mineral potential of alluvial deposits in the Challis quadrangle was appraised as follows: the location of deposits known to have produced radioactive minerals or to have been explored by drilling was plotted on the geologic map. Significant alluvial deposits were outlined on the geologic map and their location with respect to surrounding geology, stream deposition, and source was considered. Published and unpublished information on alluvial deposits was studied. On the basis of these investigations, 18 areas (labeled A-R, pl. 23) that contain significant alluvial deposits were identified as study areas. The resource potential of each study area was then appraised, using the following criteria.

Diagnostic criteria

1. Alluvium contains monazite or radioactive minerals.
2. Alluvial deposit is large; contains more than 10 million yd^3.
3. Alluvium is derived from an area that was extensively glaciated.
4. Alluvium is in valleys of low stream gradient.
5. Alluvium is underlain by or near extensive exposures of granitic rock, from which the alluvium was derived.

Permissive criteria

1. Source streams eroded extensive pre-Pleistocene land surface of decomposed granitic rock.
2. Contributing drainage basin contained glacial moraines and outwash fans that were fed and eroded by periglacial streams.
3. Gradient of transporting streams permitted winnowing of lighter minerals and rock fragments.
4. Deposit is in or at the edge of a basin containing Miocene sedimentary rocks.
5. Deposit contains more than 0.5 lb of monazite or other radioactive minerals per yd^3 of alluvium.
6. Deposit contains 5 lbs of ilmenite per yd^3.

Criteria 5 and 6 are not truly permissive, as defined by Pratt (1981), but they were placed on our permissive list in order to present additional pertinent information. Minimal mineral content is a primary consideration in appraising the potential of a placer deposit.

Scores of the appraisal criteria are tabulated in table 43. From these semiquantitative scores, the resource potential of the study areas is interpreted as:

High potential: study areas A and H.

Moderate potential: study areas B, C, D, E, G, J, K, L, and O.

Low potential: study areas F, I, M, N, P, Q, and R.

Study area A extends along the eastern side of Long Valley and contains the productive Big Creek deposit as well as several other deposits that have been explored by drilling (pl. 23, table 42). Within the area are large tracts of alluvium that have not been explored, but which have geologic characteristics similar to those of deposits that have been explored, and therefore are rated as having an excellent potential for radioactive mineral resources. The Big Meadow deposit of Bear Valley in study area H also has produced notable amounts of radioactive minerals (table 42). Downstream alluvial deposits of Bear Valley have been tested by drilling and are known to contain resources of radioactive minerals. Of particular interest is deep alluvium in the lower central part of Bear Valley, which is shown by deep drill holes to contain concentrations of monazite (Storch and Holt, 1963). Parts of study area H that have not been tested but are geologically favorable include alluvium beneath meadows along Elk Creek and Porter Creek, Ayers Creek, and along lower reaches of Fir Creek.

A moderate potential is interpreted for study areas B (Garden Valley), C (South Fork of the Salmon River), D (Deadwood Valley and upper Johnson Creek Valley), E (Whitehawk basin), G (Sulphur Creek), J (Payette River placer), K (Beaver Creek-Cape Horn Creek locality), L (Sawtooth Valley), and O (Warm Springs Creek Valley). The Williams Creek-Gold Creek deposit in Sawtooth Valley is exceptionally rich for this area and constitutes a significant known resource of radioactive materials, but exploration elsewhere in the valley, as at the Kelly Creek and Stanley Creek placers (table 42) and along Meadow Creek (Storch and Holt, 1963), was not encouraging. Extensive glacial moraines and outwash fans of late Pleistocene age along Sawtooth Valley (Williams, 1961) overlie older alluvium thereby masking it and making exploration difficult. A gravity survey of the region indicates that alluvium in Sawtooth Valley may extend to considerable depths (Mabey and Webring, 1985).

Area J contains the Payette River placer, which is along the South Fork of the Payette River, near Grandjean, and above the confluence of Trail Creek and the South Fork. The placer is almost entirely within the Sawtooth Wilderness (Kiilsgaard and Coffman, 1984). Holes drilled in the placer have outlined an enormous volume of low-grade material. Cuttings from 12 holes that ranged from 40 to 110 ft deep averaged 11.16 lb black sand per yd^3 and 4.02 lb of heavy nonmagnetic material per yard. The heavy nonmagnetic fraction was analyzed and found to have an average content of 0.320 lb Nb_2O_5 per yd^3, 0.0015 lb Ta_2O_5 per yd^3, and 0.0004 lb U_3O_8 per yd^3 (Kiilsgaard and others, 1970).

Area O contains The Meadows placer deposit, which is on Warm Springs Creek at its confluence with Pigtail Creek. The deposit is about 3.5 mi long and 0.5 to 1 mi wide, and was explored in 1957 under a Defense Minerals Exploration contract. Twenty holes drilled in the deposit indicate that depth to bedrock would exceed 100 ft over most of the deposit. Heavy-mineral concentrate from the holes ranged from 2.73 to 89.71 lb per yd^3 of placer material. Analyses of the heavy-mineral concentrate indicated an average of 0.001 lb U_3O_8 per yd^3, 0.004 lb ThO_2 per yd^3, 0.003 lb Nb_2O_5 per yd^3, 0.001 lb Ta_2O_5 per yd^3, and 0.021 lb rare earth oxides per yd^3. The exploration program showed the deposit to be subeconomic at then-current prices and costs, but it nevertheless contains significant amounts of uranium, thorium, niobium, and tantalum.

Alluvium in areas of low potential generally is along streams of high gradient. Such alluvial deposits are not thick, and commonly contain a large proportion of boulders that inhibit dredging. Many low-potential deposits show little surficial evidence of concentrations of radioactive minerals whereas others are miles distant from large exposures of granitic source-rock or from glacial moraines.

The remainder of the quadrangle, areas labeled S, has a low potential for additional radioactive black sand placer deposits due to absence of diagnostic criteria. More detailed work in these areas could bring to light evidence of the sort used to delineate potential, but no such information is known at this time.

Table 43. Recognition criteria for radioactive black sand placer deposits (see pl. 23)

Map area	Contains radio-active minerals	Large size	Extent of Pleistocene glaciation	Low stream gradient	Underlain by or near granite	Total	Streams eroded pre-Pleistocene land surface	Outwash from Pleistocene glaciers	Stream winnow-ing	Basin con-tains Miocene sediments	More than 0.5 lb radioactive minerals per yd^3	More than 5 lbs ilmenite per yd^3	Total	Resource potential
A	1	1	1	1	1	5	1	1	1	1	1	1	6	High
B	1	1	-1	1	1	3	1/2	-1	1	1	-1	-1	- 1/2	Moderate
C	1	1	1/2	1	1	4 1/2	1	1/2	1/2	-1	-1	-1	-1	Moderate
D	1	1	1	1/2	1	4 1/2	1	1	1	-1	-1	-1	0	Moderate
E	1	-1	1	1	1	3	1	1	-1	-1	1	-1	0	Moderate
F	1	-1	1	-1	1	1	1	1/2	-1	-1	0	0	- 1/2	Low
G	0	1	1	1/2	1	3 1/2	1/2	0	1/2	-1	0	0	0	Moderate
H	1	1	1	1	1	5	1	1	1	-1	1	1	4	High
I	1	-1	1	-1	1	1	1/2	1/2	0	-1	0	0	0	Low
J	1	1	1/2	1/2	1	4	1/2	1	1/2	-1	-1	-1	-1	Moderate
K	0	1	1	1/2	1	3 1/2	1/2	1	1/2	-1	0	0	1	Moderate
L	1/2	1	1	1	1	4 1/2	1/2	1	1/2	-1	0	-1	0	Moderate
M	0	-1	1/2	-1	1/2	-1	1/2	1/2	0	-1	0	0	0	Low
N	0	-1	1/2	-1	1	- 1/2	1/2	-1	1/2	-1	0	0	-1	Low
O	1	1	1/2	1/2	1/2	3 1/2	1/2	1	1	-1	-1	-1	- 1/2	Moderate
P	0	1/2	1/2	-1	1/2	1/2	0	0	0	-1	0	0	-1	Low
Q	0	1	1/2	1/2	-1	1	0	0	1	-1	0	0	0	Low
R	0	1	-1	-1	-1	-2	1/2	-1	1/2	-1	0	0	-1	Low

ROCK PRODUCTS

By Frederick S. Fisher and S. Warren Hobbs

Economic potential of the many rock types and surface materials that occur in the Challis quadrangle is severely limited by a restricted local market, remoteness from other markets, and high transportation costs. Only sand and gravel, flagstone, volcanic tuff, and granite are considered to have possible potential in the foreseeable future.

Abundant sand and gravel occur along the courses of most of the major rivers and streams in the area as a major component of the stream-bed material, as a capping on the surface of rock-cut terraces, and as the very thick deposits in locally developed constructional fill-terraces. Composition of the gravel varies with the source rock in the drainage basins of the various stream valleys within which it is found, and the degree of sorting, proportion of sand to gravel, and size range vary widely from place to place. General-purpose sand and gravel operations are restricted to the populated area along the Salmon River in and near the town of Challis and to a few small pits for the intermittent production of road metal at other places along the Salmon and Payette Rivers and a few of their major tributaries. The area contains unlimited resources of this commodity, but has a very limited market.

Flagstone is the only sedimentary building stone that has been exploited in recent years in the Challis quadrangle. A zone of maroon to greenish-gray, very platy, thin-bedded, argillaceous quartzite that occurs within the predominantly medium- to thick-bedded Clayton Mine Quartzite (Hobbs and others, 1968) is well developed at several localities on the west limb of the Bayhorse anticline (fig. 3). The most accessible locality, and the only one that was being mined in 1985, is on the ridge immediately northeast of the junction of the East Fork with the main Salmon River (fig. 3). On Squaw Creek about 1 mi upstream from the Red Bird mine (pl. 1; fig. 3), the carbonate-siltstone sequence below the Cash Creek Quartzite contains a lower interval about 65 ft thick that is composed of thin-bedded, micaceous, gray to greenish-gray and purplish-gray slate or siltstone and sandy siltstone with local layers of micaceous quartzite. The upper 25 ft of the siltstone splits along the bedding into smooth thin slabs and has been prospected for commerical flagstone (Hobbs and others, 1968). It crops out a short distance above Squaw Creek road in the narrow canyon that cuts through the thick quartzite sequence of Middle Cambrian and older age.

The Challis Volcanic Group contains many units of tuffaceous rocks, some of which have been used in the past as a source of building stone. Several of the older structures in the town of Challis and at early mining camps were constructed of blocks cut from this material. Both the tuff of Pennal Gulch and the tuff of Challis Creek that crop out near the town of Challis have apparently been used for this purpose, but other units, widely scattered in the extensive Challis volcanic field, may be equally suitable. No commercial production of tuffaceous building stone seems probable and only very limited local use may be expected in the future.

Extensive exposures of granitic rocks of the Cretaceous Idaho batholith and the Tertiary Sawtooth and Casto plutons and related smaller intrusive bodies undoubtedly contain material suitable for quarrying as building or decorative stone. Much of the Idaho batholith is light- to medium-gray granodiorite that is usually deeply weathered with few fresh outcrops. The Tertiary plutons are predominantly pink granite and generally quite fresh.

However, as with other similar commodities in the area, location, distance to market, and cost of transportation make their resource potential extremely small.

OPALITE-TYPE MERCURY VEINS

By Theresa M. Cookro and B.F. Leonard

The best example of opalite mercury veins near the Challis quadrangle is the Idaho-Almaden mine, 17 mi east of Weiser, Idaho. From 1939 to 1942, the mine produced 4,000 flasks of mercury from 53,000 tons of ore, and from 1956 to 1972 it produced about 1,000 flasks annually. Anderson (1941) describes the deposit as being in a down-warped portion of the crest of an anticline in the Tertiary (Miocene) Payette strata. The sandstones were opalized and cinnabar is contained within the opalite. Bedding planes and cross bedding are sites of concordant mineralization, and the deposit is irregular to flat. Opalite with cinnabar also follows fracture zones. Data presented in the descriptive part of this paper are wholly taken from Anderson (1941) and Ross (1956).

Mineralogically the deposit is composed of cinnabar, silica (opal and chalcedony), clay, pyrite, and limonite. The opalite has a faint vermillion color, colloform banding, and desiccation cracks. Chalcedony, the most abundant constituent of the opalite, forms coatings on cavity walls. Beidellite, kaolinite, and halloysite have been identified as the clay minerals present. The cinnabar is fine grained but with visible crystal form. Cinnabar is irregularly distributed; it fills cracks and coats surfaces. Gold values of 0.01 oz per ton were found in cinnabar-enriched areas, but the gold is believed to be associated with pyrite. Quartz, feldspar, mica, zircon, and tourmaline are found as sandstone remnants in the deposit.

The ore is within Miocene sandstones with some tuffaceous and shaly rocks. The opalized veins are both concordant to and cross cut bedding; some follow fracture zones. Steep fractures contain high-grade cinnabar veinlets; the cinnabar fills cracks and coats surfaces. The entire deposit is covered by an impermeable cap-rock of thin, partly opalized shale that overlies and forms an abrupt limit to the ore body.

Host rocks are moderately consolidated massive sandstone of the Payette Formation which contain subordinate impermeable beds of clayey and sandy shale and some fine-grained clayey sandstone. The sandstone is well sorted, moderately coarse, and rounded to subangular, with a grain size of 3-4 mm. Quartz, microcline, orthoclase, and plagioclase are the principal components of the rock; muscovite, magnetite, and zircon are accessory minerals. Both basalt beds and coal beds are intercalated within this unit. Columbia River basalt conformably overlies the Payette Formation.

We believe the faults formed the "plumbing system" for the opalization of the sandstone. Fault breccias in the region contain visible cinnabar. The N. 60° W. and N. 15° W. fracture systems contain cinnabar and have been active since the deposition of cinnabar.

Factors that appear to be critical in the Weiser-type opalite mercury deposits are:

(1) a massive, originally porous sandstone (Tertiary) that could be flooded with quartz carrying cinnabar.

(2) a thin shale layer is present in the main Weiser ore body at the top of the ore-bearing sandstone. The shale layer acted as a cap and marks the upper extent of the ore.

(3) the downwarped portion of the crest of the anticline may have formed a structural trap.

(4) the steep faults served as conduits for the mineralizing fluids.

In the Challis quadrangle, mercury has been produced from the Yellow Pine area, and is reported in Garden Valley and along Stanley Creek. At Yellow Pine, cinnabar occurs with chalcedonic quartz at the Hermes Mine. Unpublished DMEA reports (1953) describe cinnabar in veins along the west side of Garden Valley. Choate (1962) reports cinnabar in float and placer deposits along Stanley Creek.

Miocene sediments are known to occur in the Garden Valley area; they are similar, but not identical, to those at Weiser. Large structural traps are unknown, but impermeable rocks, either shales or lavas, could have acted as caps for fluid circulation in those sediments. Sandstones are locally present in the volcanotectonic subsidence structures near Yellow Pine and elsewhere in the quadrangle. High angle faults are common throughout the quadrangle. If there are any deposits analogous to the Idaho-Almaden deposit within the Challis quadrangle, we believe they will occur where the factors described above occur in combination. In our opinion, the most likely areas are Garden Valley and Yellow Pine.

URANIUM IN SEDIMENTARY ROCKS IN CONTACT ZONES WITH GRANITIC ROCKS

By Theresa M. Cookro and Kathleen M. Johnson

The Midnite, Sherwood, and Spokane Mountain mines, in eastern Washington, are examples of uranium in sedimentary rocks in contact with granitic rocks. These deposits probably result from a combination of sedimentary, hydrothermal, and supergene processes; their distribution, size, and shape are controlled by regional and local structural features. The Midnite mine has been described in several papers by Nash and coworkers (Nash, 1975; Nash and Lehrman, 1975; Nash, 1977). Work at Spokane Mountain is described by Robbins (1978).

Most of the uranium ore occurs in the sedimentary rocks. The uranium minerals include autunite, meta-autunite, pitchblende, and coffinite. They occur as disseminations along foliations, in shear zones, and in stockworks. Favorable host rocks are muscovite and chlorite schist, graphitic and pyritic mica phyllite, and calc-silicate hornfels, all in the Precambrian Togo Formation. Mineralized rock is found wherever there was adequate permeability to permit circulation of fluids. Ore bodies cut across lithologic boundaries in the Togo Formation and are found near Cretaceous(?) and Eocene granitic intrusions, but seldom extend into the granitic rocks. The notable exception is at Spokane Mountain, where minor uranium ore is found as much as 50 ft into the quartz monzonite porphyry. The ore bodies generally have a tabular habit, with subhorizontal bases and more irregular tops. The greatest thicknesses of ore are found above depressions in the contact with the granitic rocks.

Nash (1977) and Robbins (1978) speculate that these deposits may result from a combination of penesyngenetic and hydrothermal processes. In addition, remobilization and supergene enrichment may have taken place from Cretaceous time to the present. The precise timing of mineralization is not clear and the role of the granitic rocks cannot be definitively documented. However, it seems clear that the favorable factors for creation of deposits like these include: (1) a source of hypogene or supergene uranium-rich fluids and (2) sedimentary or metasedimentary host rocks with good permeability and carbonaceous, pyritic, or ferromagnesian compositions. The fluids could have either a plutonic or a volcanic source. The permeability may be either primary or secondary. Host rock composition is important to provide an environment suitable for deposition of uranium minerals.

Intrusive rocks of Tertiary age in the Challis quadrangle are known to have relatively high radioactivity (Bennett, 1980). Swanberg and Blackwell (1973) report higher uranium, thorium, and potassium in the Tertiary intrusives than in the Cretaceous intrusives. Kiilsgaard and others (1970) found high uranium concentrations in sediment samples from streams draining the Tertiary Sawtooth batholith. None of the sedimentary or metasedimentary rocks of the Challis quadrangle are precisely equivalent to the Togo Formation, but carbonaceous and pyritic rocks do occur in the area. If there are any deposits analogous to those described here, we believe they will be along contacts of the Tertiary plutonic rocks and the Precambrian and Paleozoic sedimentary and metasedimentary rocks.

HOT-SPRINGS GOLD DEPOSITS

By Theresa M. Cookro, Kathleen M. Johnson, and Frederick S. Fisher

Hot-springs gold deposits are typically low-grade, bulk-tonnage deposits, in some cases enriched by the presence of mineralized veinlets and stockworks. Because the Challis quadrangle includes geologic environments similar to those in California, Nevada, and elsewhere in the world in which such deposits are found, we believe they may be present here.

As Berger and Eimon (1983, p. 191) point out:

> Most epithermal precious-metal deposits were probably formed by hydrothermal systems that vented thermal waters to the surface in some manner. However, deposition from very hot solutions at or very near the surface results in a set of geological characteristics that set "hot springs" deposits apart from those epithermal deposits that formed at greater depths.

Our concern here is with precious metals deposited at or just below the surface, rather than with the deeper parts of such systems, which are described as other models in this assessment. Well-studied examples of these deposits include: Round Mountain, Nevada (Berger and Tingley, 1980); Hasbrouck Mountain, Divide District, Nevada (Silberman, 1982); Sulphur, Nevada (Wallace, 1980); and McLaughlin, California.

Deposits of this type are associated with silica sinter deposited at the surface. They commonly occur in volcanic or volcaniclastic rocks of predominantly felsic composition; tuff breccias or volcaniclastic rocks with a high degree of permeability can be important hosts. The presence of complex high-angle structures, such as caldera margins, and swarms of small intrusions are also positive indications. Significant characteristics include multiple episodes of silicification and brecciation, quartz + adularia + hydromica veins, and zones of hypogene argillization (Berger and Eimon, 1983). Geochemical indicator elements may include arsenic, antimony, mercury, and thallium, although if the silica cap is eroded off, most of these may also be gone.

Mineralogically these deposits are quite simple. Pyrite is the most common sulfide and the ore mineral is gold, with variable amounts of silver included. In various deposits arsenopyrite, fluorite, sphalerite, cinnabar, and sulfur have been reported (Berger and Tingley, 1980; Wallace, 1980). Gangue minerals include quartz, adularia, sericite, kaolinite, and alunite (Silberman, 1982).

Hot springs are common in the Challis quadrangle. However, none are thought to be related to cooling igneous bodies and only two small outcrops of calcareous tufa deposited by hot springs active in Quaternary time have been mapped (Hays and others, 1978). There is no evidence that juvenile water or chemical components from cooling magmas are being added to any of the hot springs.

Fifteen samples from Sunbeam hot springs (44°16′ N., 114°45′ W.) and three travertine terraces in Round Valley were analyzed for gold by atomic-absorption methods. Gold was found in four samples, at a detection limit of 0.05 ppm. The gold-bearing samples came from two different terraces located one-half mile apart southwest of Bradbury Flat (44°25′ N., 114°11′ W.). In addition, four samples of algae from Sunbeam hot springs have been analyzed. Gold values range from 0.002 to 0.024 ppm; the samples yielded 43-84 percent ash, indicating that they were contaminated with sediment and casting doubt on the absolute gold content of the algae. Based on these samples, we conclude that the potential for economic hot-springs gold deposits in the Challis quadrangle is small.

VEIN AND REPLACEMENT ALUNITE DEPOSITS

<u>By</u> Kathleen M. Johnson

Vein and replacement alunite deposits are found in volcanic terranes throughout the western U.S. and elsewhere in the world. In the U.S. these terranes are of Tertiary age, as are the alunite deposits; terranes and deposits of various ages are known elsewhere. Both the veins and the replacement deposits result from interaction of strongly acidic volcanogenic fluids with volcanic host rocks. Both types of deposits form in near-surface environments. At Marysvale, Utah, the veins are coarsely crystalline, high-grade deposits, while the replacements are lower grade but much higher tonnage (Hall, 1982; Cunningham and others, 1984). As a result, the principal alunite resource at Marysvale, as elsewhere, is in the large-tonnage, lower-grade replacement deposits.

The vein deposits, as described by Cunningham and others (1984), filled fractures that range in size from microfractures to open fissures as wide as 70 ft. They are nearly vertical and the larger veins extend more than 330 ft below the surface; some bottom out in stockworks. The alunite consists of aggregates of light pink- to salmon-colored crystals up to 1 cm long. Little coeval quartz or kaolinite is present. Several lines of geologic evidence suggest that the veins are located above an unexposed stock, to which they are genetically related. Fluid-inclusion and sulfur-isotope data indicate that they formed in a wet-steam system from components that were derived from the underlying rocks.

The replacement deposits, also described by Cunningham and others (1984), formed in discrete cells around the margins of a known Tertiary intrusive. The cores of these altered cells are alunite, while the peripheries are kaolinite. They are also vertically zoned, passing with increasing depth from a flooded silica cap to hematitic alteration, jarositic alteration, alunitic alteration, and finally propylitic alteration. The maximum depth of alunite is 330 ft below the surface. The alunite occurs as massive, fine-grained, white to light pink aggregates that are slightly denser than less altered rock. These deposits are thought to have formed near the paleosurface in a shallow hydrothermal environment in which oxidation of hypogene H_2S was a controlling factor; the sulfur was derived from evaporite beds in underlying sediments. The intrusive was involved only as a heat source. The location and size of cells was determined by local permeability of the volcanic host rocks.

The calderas and volcanotectonic grabens of the Challis volcanic field are potentially favorable localities for the formation of both vein and replacement alunite deposits. Shallow intrusions are common and permeable host rocks occur as caldera fill in numerous areas. Any alunite deposits occurring in the Challis quadrangle would probably differ in detail from the general descriptions above, but should occur in similar terranes and result from similar processes. The resource potential for these types of deposits is unknown.

SILVER DEPOSITS IN CALDERA-FILLING LAKE SEDIMENTS

By Frederick S. Fisher and Kathleen M. Johnson

Stratigraphic, structural, and mineralogical environments in calderas of the Challis volcanic field are analogous to those in the Creede mining district of southwestern Colorado. At Creede, silver is found as disseminations in caldera-filling sandstone and conglomerate of the Creede Formation. The disseminated deposit at Bachelor Mountain is 3,000-3,500 ft long, 250-1,600 ft wide, and 130-140 ft thick (Rice, 1984) and is adjacent to the high-grade silver-base metal-bearing Amethyst vein. Smith (1981) estimates that reserves in the disseminated deposit are about 3.348 million tons at a grade of 6.39 oz silver per ton.

The deposit is located near and below the base of the Monkeymeyer Sandstone and occurs as interstitial fillings disseminated through the matrix of the conglomerate and sandstone. The richest ores occur in silicified rocks, most commonly associated with zones of carbonaceous material.

Silicification decreased in intensity away from the Amethyst vein. Near the vein, rocks are commonly totally replaced by silica. Farther away, only the matrix of conglomerates is replaced. At a distance of about 1,000 ft, rocks have been only slightly silicified.

Acanthite is the dominant silver mineral. Most of the mineralization is disseminated. Small feeder veinlets of quartz and barite are present near the hanging wall of the Amethyst vein (Rice, 1984).

The fluids that deposited the silver ores were derived from those that formed the nearby high-grade deposits in the Amethyst and OH veins. Ore deposition in the Creede Formation was controlled in part by boiling and subsequent cooling, with accompanying increase of pH, and in part by the reducing environment that resulted from fluid contact with organic trash (Barton and others, 1977; Rice, 1984). Stratigraphic control was exerted by the permeability and porosity of the conglomerates and by the relatively impermeable barrier presented by the Monkeymeyer Sandstone.

In the Challis quadrangle, the Thunder Mountain and Twin Peaks calderas and the Panther Creek and Custer grabens (fig. 1) all contain in-fillings of carbonaceous volcaniclastic sedimentary rocks. Most of these sedimentary rocks predate nearby precious-metal vein deposits and all contain both permeable units suitable for ore hosts and impermeable units which could act as barriers. Although the details of fluid movement and ore deposition would undoubtedly be somewhat different in these hypothetical ore deposits, we believe that deposits analogous to those at Creede may be present in the Challis quadrangle. The resource potential of these speculative deposits is unknown.

CARLIN-TYPE CARBONATE-REPLACEMENT GOLD DEPOSITS

By Wayne E. Hall, Theresa M. Cookro, and S. Warren Hobbs

The Carlin-type epithermal carbonate replacement deposits, in which gold occurs as very fine grained disseminations, are known principally in central and eastern Nevada (Radtke and others, 1980). These deposits exhibit the following features: (1) they form by the replacement of carbonate minerals in thin-bedded, argillaceous, arenaceous carbonate host rocks; (2) they range in grade from 4-8 gm Au/ton and have a high ratio of gold to silver; (3) they commonly have a replacement body of jasperoid adjacent to and above the ore body; (4) high-angle faults are important ore controls; (5) the ores are characterized by a distinctive set of trace elements--arsenic is the most abundant (100-1,000 ppm) and is associated with antimony (10-50 ppm), mercury (1-30 ppm), and thallium; (6) the ore bodies range from 5 to 80 million tons; and (7) most of the deposits have been found in the upper part of the Roberts Mountain Formation that is exposed in windows below the regional Roberts Mountain thrust fault.

Similar large disseminated gold deposits have not been recognized in the Challis quadrangle or adjacent areas, although the geologic setting in places is very similar to that of the Carlin area. Areas with comparable geologic settings include:

(1) Squaw Creek and Kinnikinic Creek (fig. 3), where the upper plate Salmon River assemblage is thrust over Ordovician and Cambrian quartzite and carbonate sequences within the carbonate terrane;

(2) The upper Slate Creek area (fig. 4), where the Grand Prize Formation lies in thrust fault contact over the upper silty carbonate beds in the upper part of the Salmon River assemblage. In both these areas, Cretaceous plutons are present that could have been heat sources for convective hydrothermal systems;

(3) The Yellow Pine area, where similar processes of mineralization are recognized. The terrane at Yellow Pine includes Precambrian metasedimentary rocks, Cretaceous Idaho batholith, and Eocene Challis Volcanic Group. Deposits containing arsenic, antimony, mercury, tungsten, gold, and silver are within carbonate sequences of the Yellowjacket Formation as described by Cooper (1951) and Leonard (in press); and

(4) In the Lone Pine Peak quadrangle east of the Bayhorse district and north of the Spar Canyon road, strata that are considered to be correlative with the Roberts Mountain Formation are extensively exposed (Hobbs and others, in press). Factors related to the possible occurrence of carbonate-replacement gold deposits are the presence of thrust and steep faults that cut the Roberts Mountain Formation and the local presence of extensive jasperoid replacement of parts of the carbonate-bearing strata. No evidence of Cretaceous plutonic activity has been identified in the area, but scattered small volcanic vent flows and breccias related to the Eocene Challis Volcanic Group suggest subjacent igneous activity that may have produced convective hydrothermal systems.

STRATABOUND COPPER-SILVER DEPOSITS IN PRECAMBRIAN QUARTZITES

By Earl H. Bennett, Idaho Geological Survey

There are numerous occurrences of stratabound copper-silver mineralization in rocks of the Belt Supergroup of Precambrian age in northern Idaho and western Montana. Many of these are in the Revett Quartzite of the Ravalli Group. Best known of the Revett-stratabound deposits is the Troy mine, which began production in 1982 and produces over 4 million ounces of silver and 19,000 tons of copper per year. This type of deposit is a low-grade (average 1.5 oz Ag and 0.74 percent Cu), high-tonnage deposit requiring bulk mining techniques for profitable operation. Mineralized rocks at the Troy mine are described by Hayes (1984) and Dayton (1983).

Precambrian rocks that may be equivalent to the Belt Supergroup units occur in the northeast corner of the Challis quadrangle. The Yellowjacket Formation is similar in many ways to the Prichard Formation, and the Hoodoo Quartzite may be equal to the Revett Quartzite. Ruppel (1975) suggested that the Hoodoo was equivalent to the Big Creek Quartzite in his Lemhi Group. Ekren (in press) has questioned the validity of the Hoodoo Quartzite which he suggests may be part of the Yellowjacket Formation. Bennett (1977) and Lund and others (1983) suggest that outcrops of white quartzite that were mapped as Hoodoo or Big Creek Quartzite in the vicinity of the Blackbird mine are allochthonous.

If the Hoodoo Quartzite is part of the Yellowjacket Formation, the comparison with stratabound copper-silver deposits in the Revett Formation is moot. If the Hoodoo Quartzite is equivalent to the Revett Quartzite, then there is a remote chance that similar copper-silver deposits could exist; however, the areal extent of white quartzite in the Challis map area is very limited and no signs of stratabound copper-silver deposits were found during field work. Overall, the potential for stratabound copper-silver deposits in the Precambrian white quartzites in the Challis quadrangle is very low.

REFERENCES CITED

Adams, J.W., 1968, Rhabdophane from a rare-earth occurrence, Valley County, Idaho: U.S. Geological Survey Professional Paper 600-B, p. B48-B51.

Anderson, A.L., 1934, Geology of the Pearl-Horseshoe Bend gold belt, Idaho: Idaho Bureau of Mines and Geology Pamphlet 41, 36 p.

______1941, Geology of the Idaho-Almaden Quicksilver Mine near Weiser, Idaho: Idaho Bureau of Mines and Geology Pamphlet 55, 9 p.

______1942, Endomorphism of the Idaho batholith: Geological Society of America Bulletin, v. 53, no. 8, p. 1099-1126.

______1943a, Antimony and fluorspar deposits near Meyers Cove, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 62, 20 p.

______1943b, A preliminary report on the cobalt deposits in the Blackbird district, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 61, 34 p.

______1947, Geology and ore deposits of the Boise Basin, Idaho: U.S. Geological Survey Bulletin 944-C, 319 p.

______1948, Role of the Idaho batholith during the Laramide orogeny: Economic Geology, v. 43, no. 2, p. 84-99.

______1949, Silver-gold deposits of the Yankee Fork district, Custer County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 83, 37 p.

______1951, Metallogenic epochs in Idaho: Economic Geology, v. 46, no. 6, p. 592-607.

______1952, Multiple emplacement of the Idaho batholith: Journal of Geology, v. 60, no. 3, p. 255-265.

______1953, Gold-copper-lead deposits of the Yellowjacket district, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 94, 41 p.

______1954a, A preliminary report on the fluorspar mineralization near Challis, Custer County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 101, 12 p.

______1954b, Fluorspar deposits near Meyers Cove, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 98, 34 p.

______1961, Geology and mineral resources of the Lemhi quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines Geology Pamphlet 124, 111 p.

Anderson, A.L., and Rasor, A.C., 1934, Silver mineralization in the Banner district, Boise County, Idaho: Economic Geology, v. 29, no. 4, p. 371-387.

Armstrong, R.L., 1976, The geochronometry of Idaho: Isochron/West, no. 15, 51 p.

Back, J.M., 1982, Petrologic characteristics of igneous rocks in the Van Horn Peak cauldron complex, Salmon River Mountains, central Idaho: Eugene, Oregon, University of Oregon, M.S. thesis, 205 p.

Baker, D.J., 1985, Geology of the Cumo molybdenum-copper system, Boise County, Idaho: Geological Society of America Abstracts with Programs, v. 17, no. 4, p. 207.

Ballard, S.M., 1924, Geology and gold resources of the Boise Basin, Boise County, Idaho: Idaho Bureau of Mines and Geology Bulletin 9, 103 p.

Bankey, V.L., Webring, M.W., Mabey, D.R., Kleinkopf, M.D., and Bennett, E.H., 1985, Complete Bouguer anomaly map of Idaho: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1773.

Barton, P.B., Jr., Bethke, P.M., and Roedder, Edwin, 1977, Environment of ore deposition in the Creede mining district, San Juan Mountains, Colorado: Part III. Progress toward interpretation of the chemistry of the ore-forming fluid for the OH vein: Economic Geology, v. 72, p. 1-24.

Bateman, P.C., Clark, L.D., Huber, N.K., Moore, J.G., and Rinehart, C.D., 1963, The Sierra Nevada batholith--a synthesis of recent work across the central part: U.S. Geological Survey Professional Paper 414-D, p. D1-D46.

Bell, R.N., 1913, Fourteenth annual report of the mining industry of Idaho for the year 1912: p. 68-70, 92-95, 98-101.

Bennett, E.H., 1977, Reconnaissance geology and geochemistry of the Blackbird Mountain--Panther Creek Region, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 167, 108 p.

______1980, Granitic rocks of Tertiary age in the Idaho batholith and their relation to mineralization: Economic Geology, v. 75, no. 2, p. 278-288.

______1984, The trans-Challis fault zone--A major crustal discontinuity in central Idaho: Geological Society of America Abstracts with Programs, v. 16, p. 442.

Bennett, E.H., and Knowles, C.R., 1985, Tertiary plutons and related rocks in central Idaho, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis $1^o x 2^o$ quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 81-95.

Berger, B.R., and Eimon, P.I., 1983, Conceptual models of epithermal precious metal deposits, in Shanks, W.C. III, ed., Cameron Volume on Unconventional Mineral Deposits: Society of Mining Engineers of AIME, p. 191-205.

Berger, B.R., and Tingley, J.V., 1980, Geology and geochemistry of the Round Mountain gold deposit, Nye County, Nevada [abs.]: Society of Mining Engineers of AIME, Northern Nevada Section, Precious Metals Symposium, p. 18c.

Bradley, Worthen, 1943, The Hermes quicksilver mines: Mining Congress Journal, v. 29, no. 11, p. 32-34; no. 12, p. 40-44.

Breckenridge, R.M., Sprenke, K.F., and Stryhas, B.A., 1984, List of Idaho earthquakes 1872-1983: Idaho Bureau of Mines and Geology Technical Report 84-1.

Brobst, D.A., 1973, Barite, in Brobst, D.A., and Pratt, W.P., eds., United States mineral resources: U.S. Geological Survey Professional Paper 820, p. 75-84.

Brooks, P.T., and Potter, G.M., 1974, Recovering vanadium from dolomitic Nevada shale: U.S. Bureau of Mines Report of Investigations 7932, 20 p.

Bunning, B.B., and Burnet, F.W., 1981, Copper-molybdenum mineralization in the Bobcat Gulch porphyry system, Lemhi County, Idaho: Paper presented at the 87th Annual Northwest Mining Association Convention, Spokane, Wash., 11 p.

Callahan, J.E., Cooley, E.F., and Neuerburg, G.J., 1981a, Selected Mo and W assays from stream-sediment samples and panned heavy-mineral concentrates, Challis, Idaho 2^o topographic quadrangle: U.S. Geological Survey Open-File Report 81-1344, 12 p.

______1981b, Using the minus-200 mesh fraction in regional stream sediment surveys for Mo-W--results from the Thompson Creek drainage, Idaho [abs.]: AIME, 1981 fall meeting, Denver, Abstracts with programs, p. 49.

Carne, R.C., and Cathro, R.J., 1982, Sedimentary exhalative (sedex) zinc-lead-silver deposits, northern Canadian Cordillera: Canadian Institute of Mining Bulletin 75, p. 66-78.

Cater, F.W., Pinckney, D.M., Hamilton, W.B., Parker, R.L., Weldin, R.D., Close, T.J., and Zilka, N.T., 1973, Mineral resources of the Idaho Primitive Area and vicinity, Idaho, with a section on The Thunder Mountain district, by B.F. Leonard, and a section on Aeromagnetic interpretation, by W.D. Davis: U.S. Geological Survey Bulletin 1304, 431 p.

Cavanaugh, P.C., 1979, The geology of the Little Boulder Creek molybdenum deposit, Custer County, Idaho: Missoula, Mont., University of Montana M.S. thesis, 100 p.

Chambers, A.E., 1966, Geology and mineral resources of part of the Bayhorse Mining District, Custer County, Idaho: Tucson, Ariz., University of Arizona Ph.D. thesis.

Choate, Raoul, 1962, Geology and ore deposits of the Stanley area: Idaho Bureau of Mines and Geology Pamphlet 126, 120 p.

Churkin, Michael, Jr., 1963, Ordovician trilobites from graptolitic shale in central Idaho: Journal of Paleontology, v. 37, p. 421-428, pl. 51.

Constantopoulos, J.T., 1985, Fluid inclusions and geochemistry of fluorite from the Challis quadrangle, Idaho: Geological Society of America Abstracts with Programs, v. 17, no. 4, p. 214.

Cook, E.F., 1956, Tungsten deposits of south-central Idaho: Idaho Bureau of Mines and Geology Pamphlet no. 108.

______1959, Geology of the uranium deposits near Stanley, Custer County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 117.

Cook, J.R., and Fay, W.M., 1982, Data report--western United States: U.S. Department of Energy Open-File Report GJBX-132-(82); available from Bendix Field Engineering Corp., P.O. Box 1569, Grand Junction, Colo. 81502-1569.

Cookro, T.M., 1983, Tungsten deposits in the Challis quadrangle, Idaho: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 299.

______1985, Depositional controls of breccia-fill and skarn tungsten deposits in the Challis quadrangle, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis $1^{o}x2^{o}$ quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 193-201.

Cookro, T.M., and Petersen, M.A., 1984, Breccia-fill tungsten deposits in central Idaho: Geological Society of America Abstracts with Programs, v. 16, no. 5, p. 276.

Cooper, J.R., 1951, Geology of the tungsten, antimony, and gold deposits near Stibnite, Idaho: U.S. Geological Survey Bulletin 969-F, p. 151-197.

Cox, D.C., 1954, Fluorspar deposits near Meyers Cove, Lemhi County, Idaho: U.S. Geological Survey Bulletin 1015-A, 21 p.

Criss, R.E., and Champion, D.E., 1984, Magnetic properties of granitic rocks from the Idaho batholith--Influences of hydrothermal alteration and implications for aeromagnetic interpretation: Journal of Geophysical Research, v. 89, p. 7061-7076.

Criss, R.E., Champion, D.E., and McIntyre, D.H., 1985, ^{18}O, aeromagnetic, and gravity anomalies associated with hydrothermally altered zones in the Yankee Fork mining district, Custer County, Idaho: Economic Geology, v. 80, no. 5, p. 1277-1296.

Criss, R.E., Ekren, E.B., and Hardyman, R.F., 1984, Casto ring zone: A 4,500-km^2 fossil hydrothermal system in the Challis volcanic field, central Idaho: Geology, v. 12, p. 331-334.

Criss, R.E., and Taylor, H.P., Jr., 1983, An $^{18}O/^{16}O$ and D/H study of Tertiary hydrothermal systems in the southern half of the Idaho batholith: Geological Society of America Bulletin, v. 94, no. 5, p. 640-663.

Cunningham, C.G., Rye, R.O., Steven T.A., and Mehnert, H.A., 1984, Origins and exploration significance of replacement and vein-type alunite deposits in the Marysvale volcanic field, west central Utah: Economic Geology, v. 79, no. 1, p. 50-71.

Currier, L.W., 1935, A preliminary report on the geology and ore deposits of the eastern part of the Yellow Pine district, Idaho: Idaho Bureau of Mines and Geology Pamphlet 43, 27 p.

Dayton, S.H., 1983, Asarco's Troy mine: Engineering and Mining Journal, February 1983, p. 40-46.

Desborough, G.A., and Poole, F.G., 1983, Metal concentrations in some marine black shales of the United States, in Shanks, W.C. III, ed., Cameron Volume on Unconventional Mineral Deposits: Society of Mining Engineers of AIME, p. 99-110.

Doe, B.R., and Stacey, J.S., 1974, The application of lead isotopes to the problem of ore genesis and ore prospect evaluation--A review: Economic Geology, v. 69, p. 757-776.

Donovan, P.R., 1962, The geology of the Little Falls area, Boise County, Idaho: Golden, Colo., Colorado School of Mines M.S. thesis, 111 p.

Dover, J.H., 1980, Status of the Antler orogeny in central Idaho--clarification and constraints from the Pioneer Mountains, in Fouch, T.D., and Magathan, E.R., eds., Paleozoic paleogeography of the west-central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Rocky Mountain paleogeography symposium 1, Denver, Colo., 1980, Proceedings, p. 1-15.

______1981, Geology of the Boulder-Pioneer wilderness study area, Chap. B, in Simons, F.S., Dover, J.H., Mabey, D.R., Tuchek, E.T., and Ridenour, J., Mineral resources of the Boulder-Pioneer study area, Blaine and Custer Counties, Idaho: U.S. Geological Survey Bulletin 1497.

Earhart, R.L., 1986, Descriptive model of Blackbird Co-Cu, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 142.

Eilerstein, D.E., and Lamb, F.D., 1956, A comprehensive report of exploration by the Bureau of Mines for thorium and radioactive black mineral deposits: U.S. Bureau of Mines RME 3140, 45 p., issued by the U.S. Atomic Energy Commission, Technical Information Service, Oak Ridge, TN.

Ekren, E.B., 1985, Eocene cauldron-related volcanic events in the Challis quadrangle, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis $1^o x 2^o$ quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 45-58.

______in press, Stratigraphic and structural relations of the Hoodoo Quartzite and Yellowjacket Formation of Middle Proterozoic age from Hoodoo Creek eastward to Mount Taylor, central Idaho: U.S. Geological Survey Bulletin 1570.

Engineering and Mining Journal, 1980, Reopening of the Blackbird mine--a possible comeback for U.S. cobalt: v. 181, no. 1, p. 29, 31.

Erdman, J.A., Leonard, B.F., and McKown, D.M., 1983, A case for plants in exploration--Gold in douglas-fir at the Red Mountain stockwork, Yellow Pine district, Idaho [abs.], in Fisher, F.S., and Johnson, K.M., Abstracts of the symposium on the geology and mineral deposits of the Challis $1^o x 2^o$ quadrangle, Idaho: U.S. Geological Survey Open-File Report 83-836, p. 10.

Erdman, J.A., Leonard, B.F., and McKown, D.M., 1985, A case for plants in exploration--Gold in douglas-fir at the Red Mountain stockwork, Yellow Pine district, Idaho, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis $1^{o}x2^{o}$ quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 141-152.

Erdman, J.A., and Modreski, P.J., 1984, Copper and cobalt in aquatic mosses and stream sediments from the Idaho Cobalt Belt: Journal of Geochemical Exploration, v. 20, p. 75-84.

Evans, K.V., and Zartman, R.E., 1981, U-Th-Pb zircon geochronology of Proterozoic Y granitic intrusions in the Salmon area, east-central Idaho: Geological Society of America Abstracts with Programs, v. 13, no. 4, p. 195.

Fay, W.M., and Cook, J.R., 1982, Gold analyses by neutron activation from SRL NURE samples: U.S. Department of Energy Open-File Report GJBX-135(82); available from Bendix Field Engineering Corp., P.O. Box 1569, Grand Junction, Colo. 81502-1569.

Fischer, R.P., 1973, Vanadium, in Brobst, D.A., and Pratt, W.P., eds., United States mineral resources: U.S. Geological Survey Professional Paper 820, p. 679-688.

Fisher, F.S., 1985, Summary of the geology, mineral deposits, and resource potential for selected commodities in the Challis quadrangle, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis $1^{o}x2^{o}$ quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 1-27.

Fisher, F.S., and May, G.D., 1983, Geochemical characteristics of the metalliferous Salmon River sequence, central Idaho: U.S. Geological Survey Open-File Report 83-670, 28 p.

Fisher, F.S., McIntyre, D.H., and Johnson, K.M., 1983, Geologic map of the Challis $1^{o}x2^{o}$ quadrangle, Idaho: U.S. Geological Survey Open-File Report 83-523, 41 p., 2 oversize sheets, scale 1:250,000.

Fisher, F.S., McIntyre, D.H., and Johnson, K.M., in press, Geologic map of the Challis $1^{o}x2^{o}$ quadrangle, Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-1819, scale 1:250,000.

Foster, Fess, and Cooley, E.F., 1982, Semiquantitative spectrographic analyses of rocks from the Mount Jordan vicinity, Custer County, Idaho: U.S. Geological Survey Open-File Report 82-467, 13 p.

Fryklund, V.C., Jr., 1951, A reconnaissance of some Idaho feldspar deposits, with a note on the occurrence of columbite and samarskite: Idaho Bureau of Mines and Geology Pamphlet 91, 26 p.

Gordon, Mackenzie, Jr., 1975 [1976], Brachiopoda of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming: U.S. Geological Survey Professional Paper 848-D, p. D1-D86, 13 pls.

Grimes, D.J., and Marranzino, A.P., 1968, Direct-current arc and alternating-current spark emission spectrographic field methods for the semiquantitative analysis of geologic materials: U.S. Geological Survey Circular 591, 6 p.

Hahn, G.A., and Hughes, G.J., Jr., 1984, Sedimentation, tectonism, and associated magmatism of the Yellowjacket Formation in the Idaho Cobalt Belt, Lemhi County, Idaho, in Hobbs, S.W., ed., The Belt: Montana Bureau of Mines and Geology Special Publication 90, p. 65-67.

Hall, R.B., 1982, Model for hydrothermal alunite deposits, in Erickson, R.L., ed., Characteristics of mineral deposit occurrences: U.S. Geological Survey Open-File Report 82-795, p. 148-154.

Hall, W.E., 1985, Stratigraphy of and mineral deposits in middle and upper Paleozoic rocks of the black-shale mineral belt, central Idaho, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis 1°x2° quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 117-131.

Hall, W.E., Batchelder, J.N., and Douglass, R.C., 1974, Stratigraphic section of the Wood River Formation, Blaine County, Idaho: U.S. Geological Survey Journal of Research, v. 2, no. 1, p. 89-95.

Hall, W.E., Rye, R.O., and Doe, B.R., 1978, Wood River mining district, Idaho--intrusion-related lead-silver deposits derived from country rock source: U.S. Geological Survey Journal of Research, v. 6, no. 5, p. 579-592.

Hall, W.E., Schmidt, E.A., Howe, S.S., and Broch, M.J., 1984, The Thompson Creek, Idaho, porphyry molybdenum deposit--an example of a fluorine-deficient molybdenum granodiorite system: Proceedings of the Sixth Quadrennial IAGOD Symposium, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, Germany, p. 349-357.

Hardyman, R.F., 1981, Twin Peaks caldera of central Idaho: Montana Geological Society Field Conference and Symposium Guidebook, southwest Montana, p. 317-322.

______1985, The Twin Peaks caldera and associated ore deposits, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis 1°x2° quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 97-105.

Hardyman, R.F., and Fisher, F.S., 1985, Rhyolite intrusions and associated mineral deposits in the Challis volcanic field, Challis quadrangle, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis 1°x2° quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 167-179.

Hayes, T.S., 1984, The relation between stratabound copper-silver ore and Revett Formation sedimentary facies at Spar Lake, Montana, in Hobbs, S.W., ed., The Belt: Montana Bureau of Mines and Geology Special Publication 90, p. 63-64.

Hays, W.H., Harris, A.G., Dutro, J.T., Jr., and Ross, R.J., Jr., 1980, Stratigraphic sections of Middle Paleozoic rocks in the vicinity of Spar Canyon, Custer County, Idaho: U.S. Geological Survey Open-File Report 80-1097.

Hays, W.H., McIntyre, D.H., and Hobbs, S.W., 1978, Geologic map of the Lone Pine Peak quadrangle, Custer County, Idaho: U.S. Geological Survey Open-File Report 78-1060.

Hobbs, S.W., 1980, The Lawson Creek Formation of middle Proterozoic age in east-central Idaho: U.S. Geological Survey Bulletin 1482-E.

______1985, Precambrian and Paleozoic sedimentary terranes in the Bayhorse area of the Challis quadrangle, in McIntyre, D.H., ed., Symposium on the geology and mineral resources of the Challis 1°x2° quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 59-68.

Hobbs, S.W., Hays, W.H., and McIntyre, D.H., in press, Geologic map of the Bayhorse area, central Custer County, Idaho: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-1882.

Hobbs, S.W., Hays, W.H., and Ross, R.J., Jr., 1968, The Kinnikinic Quartzite of central Idaho--redefinition and subdivision: U.S. Geological Survey Bulletin 1254-J, p. J1-J22.

Howe, S.S., and Hall, W.E., 1985, Light-stable isotope characteristics of ore systems in central Idaho, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis 1°x2° quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 183-192.

Hughes, G.J., Jr., 1982, Basinal setting of the Idaho cobalt belt, Blackbird mining district, Lemhi County, Idaho, in The genesis of Rocky Mountain ore deposits--Changes with time and tectonics: Denver Region Exploration Geologists Society Symposium, Denver, Colo., 1982, Proceedings, p. 21-27.

Hyndman, D.W., 1983, The Idaho batholith and associated plutons, Idaho and western Montana: Geological Society of America Memoir 159, p. 213-240.

Jennings, E.P., 1906, The Lost Packer copper-gold lode: Journal of the Canadian Mining Institute, v. 9, p. 54-57.

Johnson, K.M., and McIntyre, D.H., 1983, Disseminated gold-silver deposit in a rhyolite dome at the Sunbeam mine, Custer County, Idaho: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 324.

Kelly, H.J., Strandberg, K.G., and Mueller, J.I., 1956, Ceramic industry development and raw-material resources of Oregon, Washington, Idaho, and Montana: U.S. Bureau of Mines Information Circular 7752, 77 p.

Kern, B.F., 1959, Geology of the uranium deposits near Stanley, Custer County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 117.

Ketner, K.B., 1983, Strata-bound, silver-bearing iron, lead, and zinc sulfide deposits in Silurian and Ordovician rocks of allochthonous terranes, Nevada and northern Mexico: U.S. Geological Survey Open-File Report 83-792, 6 p.

Kiilsgaard, T.H., 1949, The geology and ore deposits of the Boulder Creek mining district, Custer County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 89.

______1950, The geology and ore deposits of the Triumph-Parker mine mineral belt, in Anderson, A.L., Kiilsgaard, T.H., and Fryklund, V.C., Jr., Detailed geology of certain areas in the Mineral Hill and Warm Springs mining districts, Blaine County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 90.

______1982, Analytical determinations from samples taken in the Ten Mile West Roadless Area, Boise and Elmore Counties, Idaho: U.S. Geological Survey Open-File Report 82-1099, 34 p.

______1983a, Geologic map of the Ten Mile West Roadless Area, Boise and Elmore Counties, Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF-1500-A, scale 1:62,500.

______1983b, Geochemical map, Ten Mile West Roadless Area, Boise and Elmore Counties, Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF-1500-B.

Kiilsgaard, T.H., Benham, J.R., and Avery, D.W., 1983, Mineral resource potential of the Ten Mile West Roadless Area, Boise and Elmore Counties, Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF-1500-C.

Kiilsgaard, T.H., and Bennett, E.H., 1985, Mineral deposits in the southern part of the Atlanta lobe of the Idaho batholith and their genetic relation to Tertiary intrusive rocks and to faults, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis 1°x2° quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 153-165.

Kiilsgaard, T.H., and Coffman, J.S., 1984, Sawtooth Wilderness, Idaho, in Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., eds., Wilderness mineral potential--assessment of mineral-resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, v. 2, p. 573-576.

Kiilsgaard, T.H., Fisher, F.S., and Bennett, E.H., 1986, The trans-Challis fault system and associated precious-metal deposits: Economic Geology, v. 81, p. 721-724.
Kiilsgaard, T.H., Freeman, V.L., and Coffman, J.S., 1970, Mineral resources of the Sawtooth Primitive Area, Idaho: U.S. Geological Survey Bulletin 1319-D, 174 p.
Kiilsgaard, T.H., and Lewis, R.S., 1985, Plutonic rocks of Cretaceous age and faults in the Atlanta lobe of the Idaho batholith, Challis quadrangle, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis $1^{o}x2^{o}$ quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 29-42.
Kiilsgaard, T.H., and Van Noy, R.M., 1984, Eastern part of the Sawtooth National Recreation Area, Idaho, in Marsh, S.P., Kropschot, S.J., and Dickinson, R.G., Wilderness mineral potential--assessment of mineral-resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 569-572.
Kirkemo, Harold, Anderson, C.A., and Creasey, S.C., 1965, Investigations of molybdenum deposits in the conterminous United States, 1942-60: U.S. Geological Survey Bulletin 1182-E, 90 p.
Kleinkopf, M.D., Harrison, J.E., and Zartman, R.E., 1972, Aeromagnetic and geologic map of part of northwestern Montana and northern Idaho: U.S. Geological Survey Geophysical Investigations Map GP-830, scale 1:250,000.
Kline, M.H., and Carlson, E.J., 1954, Pearson Creek monazite placer area, Valley County, Idaho: U.S. Atomic Energy Commission RME-3134, 24 p.
Kline, M.H., Carlson, E.J., and Horst, H.W., 1955, Corral Creek placer area, Valley County, Idaho: U.S. Atomic Energy Commission RME-3135, 22 p.
Kline, M.H., Carlson, E.J., and Storch, R.H., 1951a, Big Creek placers, Valley County, Idaho: U.S. Atomic Energy Commission RME-3131, 24 p.
______1951b, Scott Valley and Horsethief Basin monazite placers, Valley County, Idaho: U.S. Atomic Energy Commission RME-3133, 22 p.
Kline, M.H., Carlson, E.J., Storch, R.H., and Robertson, A.F., 1953, Bear Valley radioactive placers, Valley County, Idaho: U.S. Atomic Energy Commission, 23 p.
Larsen, E.S., and Livingston, D.C., 1920, Geology of the Yellow Pine cinnabar mining district, Idaho: U.S. Geological Survey Bulletin 715, p. 73-83.
Leonard, B.F., 1962, Old metavolcanic rocks of the Big Creek area, in central Idaho, in Short papers in geology, hydrology, and topography: U.S. Geological Survey Professional Paper 450-B, p. B11-B15.
______in press, The Golden Gate tungsten deposit and metal anomalies in nearby soils and plants, Yellow Pine district, Valley County, Idaho: U.S. Geological Survey Open-File Report 83-835, 26 p.
Leonard, B.F., and Erdman, J.A., 1983, Preliminary report on geology, geochemical exploration, and biogeochemical exploration of the Red Mountain stockwork, Yellow Pine district, Valley County, Idaho: U.S. Geological Survey Open-File Report 83-151, 49 p.
Leonard, B.F., and Marvin, R.F., 1982 [1984], Temporal evolution of the Thunder Mountain caldera and related fractures, central Idaho, in Bonnichsen, Bill, and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 23-41.
Leszcykowski, A.M., Lowe, N.T., Ridenour, James, and Willett, S.L., 1983, Mines and prospects in the Sheep Mountain mining district, Custer County, Idaho: U.S. Bureau of Mines MLA 89-83.
Levinson, A.A., 1980, Introduction to exploration geochemistry (2d ed.): Wilmette, Ill., Applied Publishing Ltd., 924 p.

Lewis, C.F., and Lewis, R.D., 1982, Fossil evidence for Ordovician age roof pendants previously considered as Precambrian in the Idaho batholith: Geological Society of America Abstracts with Programs, v. 14, no. 5, p. 265.

Lewis, R.S., 1984, Geology of the Cape Horn quadrangle, south-central Idaho: University of Washington, M.S. thesis, 91 p.

Lewis, R.S., Kiilsgaard, T.H., and Bennett, E.H., 1985, Chemical characteristics of Cretaceous and Tertiary rocks in the southern part of the Idaho batholith: Geological Society of America Abstracts with Programs, v. 17, no. 4, p. 252.

Lindgren, W., 1898, The mining districts of the Idaho Basin and the Boise Ridge, Idaho: 18th Annual Report of the U.S. Geological Survey, p. 472-488.

Livingston, D.C., 1919, Tungsten, cinnabar, manganese, molybdenum, and tin deposits of Idaho with notes on antimony deposits, by F.A. Thompson: University of Idaho School of Mines, Bulletin 2, v. 14.

Lopez, D.A., 1981a, Stratigraphy of the Yellowjacket Formation of east-central Idaho: Golden, Colo., Colorado School of Mines Ph.D. thesis.

______1981b, Stratigraphy of the Yellowjacket Formation of east-central Idaho: U.S. Geological Survey Open-File Report 81-1088, 202 p.

Lowe, N.T., Willett, S.L., and Benjamin, D.A., 1983, Mines and prospects in the Seafoam mining district, Custer County, Idaho: U.S. Bureau of Mines MLA 87-83.

Lund, Karen, Evans, K.V., and Esparza, L.E., 1983, Mineral resource potential map of the Special Management Zone, Clear Creek, Lemhi County, Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF-1576-A, scale 1:50,000.

Luthy, S.T., 1981, The petrology of Cretaceous and Tertiary intrusive rocks of the Red Mountain-Bull Trout Point area, Boise, Custer, and Valley Counties, Idaho: Missoula, Montana, University of Montana, M.A. thesis.

Mabey, D.R., and Webring, M.W., 1985, Regional geophysical studies in the Challis quadrangle, Idaho, in McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis $1^{o}x2^{o}$ quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 69-79.

Mackin, J.H., and Schmidt, D.L., 1953, Reconnaissance geology of placer deposits containing radioactive minerals in the Bear Valley district, Valley County, Idaho: U.S. Geological Survey Open-File Report 53-0167, 21 p.

______1956, Uranium and thorium-bearing minerals in placer deposits in Idaho, in Page, L.H., Stocking, H.E., and Smith, H.B., compilers, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geological Survey Professional Paper 300, p. 375-380.

Mamet, B.L., Skipp, Betty, and Sando, W.J., 1971, Biostratigraphy of upper Mississippian and associated Carboniferous rocks in south-central Idaho: American Association of Petroleum Geologists Bulletin, v. 55, no. 1, p. 20-33.

Mansfield, G.R., 1924, Tertiary planation in Idaho: Journal of Geology, v. 32, no. 6, p. 472-488.

Mapel, W.J., Read, W.H., and Smith, R.K., 1965, Geologic map and sections of the Doublespring quadrangle, Custer and Lemhi Counties, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-464, scale 1:62,500.

Marvin, R.F., Tschanz, C.M., and Mehnert, H.H., 1973, Late Cretaceous age for molybdenite mineralization in Custer County, Idaho: Isochron/West, no. 7, p. 1.

Mathews, W.H., 1958, Geology of the Mount Garibaldi map-area, southwestern British Columbia, Canada: Geological Society of America Bulletin, v. 69, p. 161-178.

McCandless, E.O., 1982, A re-evaluation of Cambrian through middle Ordovician stratigraphy of the southern Lemhi Range: University Park, The Pennsylvania State University, M.S. thesis, 157 p.

McDanal, S.K., Cooley, E.F., and Callahan, J.E., 1984, Analytical results of stream-sediment and nonmagnetic heavy-mineral concentrate samples from portions of the Challis $1^o x 2^o$ quadrangle, Idaho: U.S. Geological Survey Open-File Report 84-634, 389 p.

McIntyre, D.H., ed., 1985, Symposium on the geology and mineral deposits of the Challis 1^o x 2^o quadrangle, Idaho: U.S. Geological Survey Bulletin 1658A-S, 227 p.

McIntyre, D.H., Ekren, E.B., and Hardyman, R.F., 1982 [1984], Stratigraphic and structural framework of the Challis Volcanics in the eastern half of the Challis $1^o x 2^o$ quadrangle, Idaho, _in_ Bonnichsen, Bill, and Breckenridge, R.M., eds., Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 3-22.

McIntyre, D.H., and Hobbs, S.W., 1978, Geologic map of the Challis quadrangle, Custer County, Idaho: U.S. Geological Survey Open-File Report 78-1059.

McIntyre, D.H., Hobbs, S.W., Marvin, R.F., and Mehnert, H.H., 1976, Late Cretaceous and Eocene ages for hydrothermal alteration and mineralization, Bayhorse district and vicinity, Custer County, Idaho: Isochron/West, no. 16, p. 11-12.

McIntyre, D.H., and Johnson, K.M., 1983, Geologic map of part of the Sunbeam Mine area: U.S. Geological Survey Open-File Report 83-329, 1 sheet, scale 1:2,400.

______1985, Epithermal gold-silver mineralization related to volcanic subsidence in the Custer graben, Custer County, Idaho, _in_ McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis $1^o x 2^o$ quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 109-115.

Mitchell, V.E., Strowd, W.B., Hustedde, G.S., and Bennett, E.H., 1981, Mines and prospects of the Challis quadrangle, Idaho: Idaho Bureau of Mines and Geology Mines and Prospects Map Series, 47 p.

Modreski, P.J., 1985, Stratabound cobalt-copper deposits in the Middle Proterozoic Yellowjacket Formation in and near the Challis quadrangle, _in_ McIntyre, D.H., ed., Symposium on the geology and mineral deposits of the Challis $1^o x 2^o$ quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, p. 203-221.

Moore, J.G., 1959, The quartz diorite boundary line in the western United States: Journal of Geology, v. 67, no. 2, p. 198-210.

Motooka, J.M., and Grimes, D.J., 1976, Analytical precision of one-sixth order semiquantitative spectrographic analysis: U.S. Geological Survey Circular 738, 25 p.

Nash, J.T., 1975, Exploration for uranium deposits in metasedimentary rocks in light of geologic studies of the Midnite Mine, Washington: U.S. Geological Survey Open-File Report 75-638, 4 p.

______1977, Geology of the Midnite Mine uranium area, Washington--Maps, description, and interpretation: U.S. Geological Survey Open-File Report 77-592, 39 p.

Nash, J.T., and Hahn, G.A., 1986, Volcanogenic character of sediment-hosted Co-Cu deposits in the Blackbird mining district, Lemhi County, Idaho--an interim report: U.S. Geological Survey Open-File Report 86-430, 29 p.
Nash, J.T., and Lehrman, N.J., 1975, Geology of the Midnite uranium mine, Stevens County, Washington: U.S. Geological Survey Open-File Report 75-402, 36 p.
Nassau, Kurt, 1978, The origins of color in minerals: American Mineralogist, v. 63, p. 219-229.
National Academy of Sciences-National Research Council, 1959, Report of the panel of columbium and tantalum, Chap. 5, of Report of the Committee on Refractory Metals: Washington, Report MAB-154-M(1), v. 2, p. 59-83.
Nelson, W.H., and Ross, C.P., 1969, Geology of the Mackay 30-minute quadrangle: U.S. Geological Survey Open-File Report, 161 p.
Nilsen, T.H., 1977, Paleogeography of Mississippian turbidites in south-central Idaho, in Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 1, p. 275-299.
O'Neill, J.M., and Lopez, D.A., 1983, Great Falls lineament, Idaho and Montana: American Association of Petroleum Geologists, Rocky Mountain Section Meeting, Billings, Montana, Book of Abstracts.
Parker, R.L., 1964, Niobium and tantalum, in Mineral and water resources of Idaho: Idaho Bureau of Mines and Geology Special Report No. 1, p. 138-143.
Pattee, E.C., Van Noy, R.M., and Weldin, R.D., 1968, Beryllium resources of Idaho, Washington, Montana, and Oregon: U.S. Bureau of Mines Report of Investigations 7148, 169 p.
Patton, W.W., 1948, Geology of the Clayton area, Custer County, Idaho: Ithaca, N.Y., Cornell University M.S. thesis.
Pennington, W.A., Trimple, B., Smith, R.B., 1974, A microearthquake survey of parts of the Snake River Plain and Central Idaho: Seismological Society of America Bulletin, v. 64, p. 307-312.
Petersen, M.A., 1984, Geology of the Quartz Creek tungsten deposit, Yellow Pine, Idaho: Kent, Ohio, Kent State University, M.S. thesis, 94 p.
Petersen, M.A., and Cookro, T.M., 1984, Brecciation and mineralization at the Quartz Creek tungsten deposit, Yellow Pine, Idaho: Geological Society of America Abstracts with Programs, v. 16, no. 5, p. 328.
Pratt, W.P., ed., 1981, Metallic mineral-resource potential of the Rolla $1^{o}x2^{o}$ quadrangle, Missouri, as appraised in September 1980: U.S. Geological Survey Open-File Report 81-518, 77 p.
Radtke, A.S., Rye, R.O., and Dickson, F.W., 1980, Geology and stable isotope studies of the Carlin gold deposit: Economic Geology, v. 75, p. 641-672.
Reid, R.R., 1963, Reconnaissance geology of the Sawtooth Range: Idaho Bureau of Mines and Geology Pamphlet 129, 37 p.
Rice, J.A., 1984, Controls on silver mineralization in the Creede Formation, Creede, Colorado: Fort Collins, Colorado State University, master's thesis, 135 p.
Richins, W.D., Smith, R.B., Langer, C.J., Zollweg, J.E., King, J.J., and Pechmann, J.C., 1985, The 1983 Borah Peak, Idaho, earthquake: relationship of aftershocks to the mainshock, surface faulting, and regional tectonics, in Stein, R.S., and Bucknam, R.C., eds., Proceedings of Workshop XXVIII on the Borah Peak, Idaho earthquake: U.S. Geological Survey Open-File Report 85-0290A, p. 285-310.

Ridenour, James, Willett, S.L., Miller, M.S., Lowe, N.T., Leszcykowski, A.M., and Benjamin, D.A., 1983, Mines and prospects in the Loon Creek mining district, Custer County, Idaho: U.S. Bureau of Mines MLA 88-83.

Robbins, D.A., 1978, Applied geology in the discovery of the Spokane Mountain uranium deposit, Washington: Economic Geology, v. 73, p. 1523-1538.

Ross, C.P., 1927, Ore deposits in Tertiary lava in the Salmon River Mountains, Idaho: Idaho Bureau of Mines and Geology Pamphlet 25, 20 p.

______1930, Geology and ore deposits of the Seafoam, Alder Creek, Little Smoky and Willow Creek mining districts, Custer and Camas Counties, Idaho: Idaho Bureau of Mines and Geology Pamphlet 33, 26 p.

______1934a, Correlation and interpretation of Paleozoic stratigraphy in south-central Idaho: Geological Society of America Bulletin, v. 45, no. 5, p. 937-1000.

______1934b, Geology and ore deposits of the Casto quadrangle, Idaho: U.S. Geological Survey Bulletin 854, 135 p.

______1936, Mining districts of the State of Idaho: Idaho Bureau of Mines and Geology Map.

______1937a, Geology and ore deposits of the Bayhorse region, Custer County, Idaho: U.S. Geological Survey Bulletin 877, 161 p.

______1937b, Some lode deposits in the northwestern part of the Boise Basin, Idaho: U.S. Geological Survey Bulletin 846-D, p. 239-276.

______1947, Geology of the Borah Peak quadrangle, Idaho: Geological Society of America Bulletin, v. 58, no. 12, p. 1085-1160.

______1956, Quicksilver deposits near Weiser, Washington, County, Idaho: U.S. Geological Survey Bulletin 1042-D.

______1962, Stratified rocks in south-central Idaho: Idaho Bureau of Mines and Geology Pamphlet 125, p. 1-126.

______1963, Evolution of ideas relative to the Idaho batholith: Northwest Science, v. 37, no. 2, p. 45-60.

Rostad, O.H., 1967, Geochemical case history at the Little Falls molybdenite prospect, Boise County, Idaho, in Symposium on Geochemical Prospecting: Canadian Geological Survey Paper 66-54, p. 249-252.

Ruppel, E.T., 1968, Geologic map of the Leadore quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-733, scale 1:62,500.

______1975, Precambrian Y sedimentary rocks in east-central Idaho: U.S. Geological Survey Professional Paper 889, Chapter A, p. 1-23.

______1978, Medicine Lodge thrust system, east-central Idaho and southwest Montana: U.S. Geological Survey Professional Paper 1031, 23 p.

______1980, Geologic map of the Patterson quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1529, scale 1:62,500.

Ruppel, E.T., Ross, R.J., Jr., and Schleicher, David, 1975, Precambrian Z and Lower Ordovician rocks in east-central Idaho: U.S. Geological Survey Professional Paper 889, Chapter B, p. 24-34.

Savage, C.N., 1961, Economic geology of central Idaho blacksand placers: Idaho Bureau of Mines and Geology Bulletin 17, 160 p.

Sawkins, F.J., 1984, Metal deposits in relation to plate tectonics: New York, Springer Verlag, 325 p.

Schmidt, D.L., 1964, Reconnaissance petrographic cross section of the Idaho batholith in Adams and Valley Counties, Idaho: U.S. Geological Survey Bulletin 1181-C, 50 p.

Schmidt, D.L., and Mackin, J.H., 1970, Quaternary geology of Long and Bear Valleys, west-central Idaho: U.S. Geological Survey Bulletin 1311-A, 22 p.

Schrader, F.C., and Ross, C.P., 1926, Antimony and quicksilver deposits in the Yellow Pine district, Idaho: U.S. Geological Survey Bulletin 780, p. 137-164.
Shacklette, H.T., and Erdman, J.A., 1982, Uranium in spring water and bryophytes at Basin Creek in central Idaho: Journal of Geochemical Exploration, v. 17, p. 221-236.
Shannon, S.S., Jr., 1971, Evaluation of copper and molybdenum geochemical anomalies at the Cumo prospect, Boise County, Idaho, in Geochemical Exploration (International Geochemical Exploration Symposium, 3rd Proc.): Canadian Institute of Mining and Metallurgy, Special volume 11, p. 247-250.
Shenon, P.J., and Ross, C.P., 1936, Geology and ore deposits near Edwardsburg and Thunder Mountain, Idaho: Idaho Bureau of Mines and Geology Pamphlet 44, 45 p.
Sheppard, R.A., 1973, Zeolites in sedimentary rocks, in Brobst, D.A., and Pratt, W.P., eds., United States Mineral Resources: U.S. Geological Survey Professional Paper 820, p. 689-695.
Silberman, M.L., 1982, Hot-spring type, large tonnage, low-grade gold deposits, in Erickson, R.L., ed., Characteristics of mineral deposit occurrences: U.S. Geological Survey Open-File Report 82-795, p. 131-143.
Singer, D.A., and Mosier, D.L., 1981, A review of mineral resource assessment methods: Economic Geology, v. 76, p. 1006-1015.
Skipp, Betty, and Hall, W.E., 1975, Structure and Paleozoic stratigraphy of a complex of thrust plates in the Fish Creek Reservoir area, south-central Idaho: U.S. Geological Survey Journal of Research, v. 3, no. 6, p. 671-689.
Skipp, Betty, Sando, W.J., and Hall, W.E., 1979, The Mississippian and Pennsylvanian (Carboniferous) systems in the United States--Idaho: U.S. Geological Survey Professional Paper 1110-AA, 42 p.
Smith, J.W., 1981, Bachelor Mountain silver deposit, Mineral County, Colorado, in Lindemann, J.W., Babcock, J.W., and King, J.R., Field trip notes, Creede Mining District: Denver Region Exploration Geologists Society, 1981 Field Trip, p. 11-18.
Snee, L.W., and Lund, Karen, 1985, Mineralization history of the central Idaho batholith: importance of fracture-controlled Cretaceous activity: Geological Society of America Abstracts with Programs, v. 17, no. 4, p. 265.
Snyder, K.D., 1978, Geology of the Bayhorse fluorite deposit, Custer County, Idaho: Economic Geology, v. 73, no. 2, p. 207-214.
Staatz, M.H., Hall, R.B., Macke, D.L., Armbrustmacher, T.J., and Brownfield, I.K., 1980, Thorium resources of selected regions in the United States: U.S. Geological Survey Circular 824, 32 p.
Steven, T.A., and Van Loenen, R.E., 1971, Clinoptilolite-bearing beds in the Creede Formation, San Juan Mountains, Colorado, in Geological Survey Research 1971: U.S. Geological Survey Professional Paper 750-C, p. C98-C103.
Stoll, W.C., 1950 [1951], Mica and beryl pegmatites in Idaho and Montana: U.S. Geological Survey Professional Paper 229, 64 p.
Storch, R.H., and Holt, D.C., 1963, Titanium placer deposits of Idaho: U.S. Bureau of Mines RI-6319, 69 p.
Streckeisen, A.L., 1973, Plutonic rocks: Classification and nomenclature recommended by the IUGS Subcommission on the Systematics of Igneous Rocks: Geotimes, v. 18, no. 10, p. 26-30.

Swanberg, C.A., and Blackwell, D.D., 1973, Areal distribution and geophysical significance of heat generation in the Idaho batholith and adjacent intrusions in eastern Oregon and western Montana: Geological Society of America Bulletin, v. 84, p. 1261-1282.

Taubeneck, W.H., 1971, Idaho batholith and its southern extension: Geological Society of America Bulletin, v. 82, no. 3, p. 1899-1928.

Taylor, R.B., and Steven, T.A., 1983, Definition of mineral resource potential: Economic Geology, v. 78, p. 1268-1270.

Thayer, P.A., and Cook, J.R., 1980, Challis $1^{o}x2^{o}$ NTMS area, Idaho--Data report: U.S. Department of Energy Open-File Report GJBX-91(80); available from Bendix Field Engineering Corp., P.O. Box 1569, Grand Junction, Colo. 81502-1569.

Theodore, Ted, and Menzie, W.D., 1984, Fluorine-deficient porphyry molybdenum deposits in the western North America Cordillera: Proceedings of the Sixth Quadrennial IAGOD Symposium, E. Schweizerbart´sche Verlagsbuchhandlung, Stuttgart, Germany, p. 463-470.

Thomasson, M.R., 1959, Late Paleozoic stratigraphy and paleotectonics of central and eastern Idaho: Madison, University of Wisconsin Ph.D. thesis, 244 p.

Treves, S.B., and Melear, J.D., 1953, The geology and ore deposits of the Seafoam mining district, Custer County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 96, 19 p.

Tschanz, C.M., Kiilsgaard, T.H., Seeland, D.A., Mabey, D.R., Frischknecht, F.C., Van Noy, R.M., Ridenour, J., Zilka, N.T., Federspiel, F.E., Evans, R.K., Tuchek, E.T., and McMahan, A.B., 1974, Mineral resources of the eastern part of the Sawtooth National Recreation Area, Custer and Blaine Counties, Idaho: U.S. Geological Survey Open-File Report 74-100, 2 vols., 667 p.

Tunyan, G.A., 1971, Interrelation of copper-molybdenum and gold-sulfide mineralization and mineralization stages in the Aigedsor ore field: Isv. AN.Arm.SSR, Nauka o Zemle, v. 24, no. 4, p. 28-37 (in Russian).

Umpleby, J.B., 1913a, Geology and ore deposits of Lemhi County, Idaho: U.S. Geological Survey Bulletin 528, 182 p.

______1913b, Some ore deposits in northwestern Custer County, Idaho: U.S. Geological Survey Bulletin 539, 104 p.

Umpleby, J.B., and Livingston, D.C., 1920, A reconnaissance in south-central Idaho embracing the Thunder Mountain, Big Creek, Stanley Basin, Sheep Mountain, and Seafoam districts: University of Idaho Bulletin, v. 15, no. 16, 22 p.

Umpleby, J.B., Westgate, L.G., and Ross, C.P., 1930, Geology and ore deposits of the Wood River region, Idaho, with a description of The Minnie Moore and nearby mines, by D.F. Hewett: U.S. Geological Survey Bulletin 814, 250 p.

U.S. Bureau of Mines, 1943, Bonanza (Hermes) mercury mine, Valley County, Idaho: U.S. Bureau of Mines War Minerals Report 106, 27 p.

Van Noy, R.M., Ridenour, James, Zilka, N.T., Federspiel, F.E., Evans, R.K., Tuchek, E.T., and McMahan, A.B., 1974, Economic appraisal, in Tschanz, C.M., Kiilsgaard, T.H., Seeland, D.A., Van Noy, R.M., Ridenour, James, Zilka, N.T., Federspiel, F.E., Evans, R.K., Tuchek, E.T., and McMahan, A.B., Mineral resources of the eastern part of the Sawtooth National Recreation Area, Custer and Blaine Counties, Idaho: U.S. Geological Survey Open-File Report 74-100, p. 315-648.

VanTrump, George, Jr., and Miesch, A.T., 1977, The U.S. Geological Survey RASS-STATPAC system for management and statistical reduction of geochemical data: Computers and Geosciences, v. 3, no. 3, p. 475-488.

Vine, J.D., and Tourtelot, E.B., 1970, Geochemistry of black shale deposits--a summary report: Economic Geology, v. 65, no. 3, p. 253-272.

Wallace, A.B., 1980, Geology of the Sulphur district, southwestern Humboldt County, Nevada: Society of Economic Geologists 1980 Field Conference, Road log and articles, p. 80-91.

White, D.E., 1940, Antimony deposits of a part of the Yellow Pine district, Valley County, Idaho--A preliminary report: U.S. Geological Survey Bulletin 922-I, p. 247-279.

_______1946, Geologic map of the Yellow Pine area, Valley County, Idaho: U.S. Geological Survey Strategic Minerals Investigation, Preliminary Map, scale 1:48,000.

Whitney, M.S., 1975, Geology of the Cumo prospect, Boise County, Idaho: Golden, Colo., Colorado School of Mines M.S. thesis, 84 p.

Williams, P.L., 1961, Glacial geology of Stanley Basin: Idaho Bureau of Mines and Geology Pamphlet 123, 29 p.

Wopat, M.A., Siegmund, B.L., and Bernardi, M.L., 1980, Uranium resource evaluation, Challis quadrangle, Idaho: Grand Junction, Colorado, Bendix Field Engineering Corporation, report prepared for U.S. Department of Energy, under contract No. EY-76-C-13-1664, 122 p.

Zietz, I., Gilbert, F.P., and Kirby, J.R., Jr., 1978 [1979], Aeromagnetic map of Idaho; color coded intensities: U.S. Geological Survey Geophysical Investigations Map GP-920, scale 1:1,000,000.