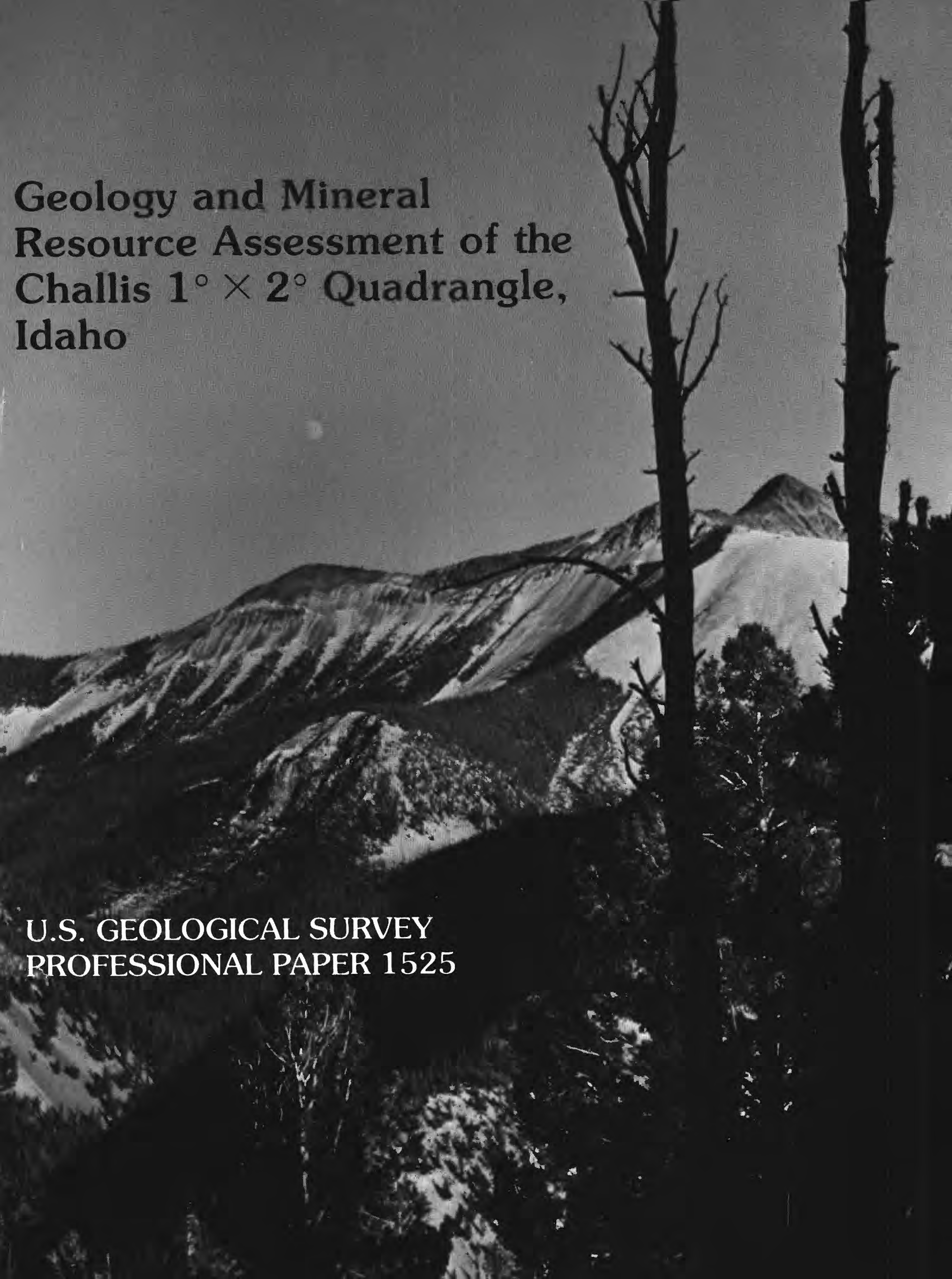
Geology and Mineral Resource Assessment of the Challis 1° × 2° Quadrangle, Idaho



U.S. GEOLOGICAL SURVEY
PROFESSIONAL PAPER 1525

Cover. Tuffs of the Challis Volcanics in the Twin Peaks Caldera, Idaho.
USGS photograph by Frederick S. Fisher.

Geology and Mineral Resource Assessment of the Challis 1°×2° Quadrangle, Idaho

Edited by Frederick S. Fisher *and* Kathleen M. Johnson

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1525

A study of the geologic and tectonic settings of mineral deposits and an assessment of the mineral resources in the Challis 1°×2° quadrangle, Idaho

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GEOLOGY AND MINERAL RESOURCE ASSESSMENT OF THE CHALLIS 1°×2° QUADRANGLE, IDAHO

Edited by Frederick S. Fisher *and* Kathleen M. Johnson

ABSTRACT

The Challis 1°×2° quadrangle, Idaho, has had modest but continuous production of mineral commodities since gold was discovered there in the 1860's. Recorded production includes more than 900,000 oz gold, 26 million oz silver, 10 million lb copper, 150 million lb lead, and 60 million lb zinc. The Bayhorse district produced silver and base metals every year from the early 1900's 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 lb combined niobium and tantalum. At the time of this compilation (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 activity. Recently, land-use has become more heavily regulated, and at present large areas of the quadrangle are affected by special mining and development regulations.

The Challis quadrangle comprises eight geologic terranes, each recognized by characteristic age, lithology, structure, and geochemical and geophysical signatures. Each terrane also has associated with it a characteristic suite of mineral commodities and types of mineral deposits. The Proterozoic terrane, in the northcentral and northeastern parts of the quadrangle, includes quartzites, argillites, and siltites and their metamorphic equivalents. The carbonate terrane, in the southeastern quarter of the quadrangle, includes Proterozoic to Mississippian limestone and dolomite. The black shale terrane trends south from the central part of the Challis quadrangle into the central part of the Hailey quadrangle and consists of metalliferous, black, siliceous-facies, clastic sedimentary rocks of Late Cambrian to Permian age. Both the carbonate terrane and the black shale terrane are cut by large thrust faults, along which the rocks were transported from the west. The west 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. Calc-alkaline extrusive and hypabyssal rocks of the Challis volcanic terrane underlie the northern and eastern parts of the quadrangle; dacitic to rhyodacitic flows, rhyolitic caldera-forming eruptive sequences, and volcaniclastic sediments crop out across these areas. The Eocene plutonic terrane comprises small to large intrusions of pink hornblende-bearing granite and gray diorite; the intrusions are scattered across the central part of the quadrangle. These six terranes are all crosscut by north- and northwest-striking high-angle faults. The alluvial terrane comprises unconsolidated or poorly consolidated fluvial deposits of Quaternary age. The trans-Challis fault system terrane is a belt of northeast-striking 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 in this study; they contain 22 commodities, including antimony, barite, 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 could contain resources of alunite, copper, gold, mercury, silver, and uranium.

Mineral resources of the Challis quadrangle were assessed by a simple subjective assessment method that depends heavily on the experience and expertise of the assessors. These assessments postulate significant resources in several deposit types. Resources of national importance include the largest known deposits of black sands in the United States, which contain rare-earth elements, monazite, and thorium; large deposits of molybdenum; probably large 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 summarizes geological, geochemical, and geophysical field and laboratory studies undertaken to assess the mineral resource potential of the Challis 1°×2° quadrangle, Idaho, as part of the Conterminous United States Mineral Assessment Program (CUSMAP) of the U.S. Geological Survey. The Challis quadrangle[1] was selected for study because it is largely 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 area of central Idaho contiguous to the quadrangle. This report and U.S. Geological Survey Miscellaneous Investigations Series Map I–1819 (Fisher and others, 1992, in pocket) constitute the Challis mineral resource folio, representing the final products of the 5-year study.

Many other maps and reports generated by the Challis CUSMAP study have been published. U.S. Geological Survey Bulletin 1658, "Symposium on the geology and mineral deposits of the Challis 1°×2° 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.

Since 1985, when field studies were finished, and 1986, when laboratory analyses were completed and final assessments made, additional fieldwork in south-central Idaho and studies in the broad field of mineral resource assessment have been conducted. The results of these later studies have not been incorporated into this report, but it is the editors' belief that these later studies will support the concepts and conclusions described here.

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 considered in assigning resource potentials to any given tract of land. Nor were any economic factors or mining feasibility taken into account in the resource appraisals. However, large areas of the quadrangle are affected by special mining and development regulations.

Frederick S. Fisher and Kathleen M. Johnson edited this report. Authorship of the numerous individual sections is shown at the beginning of each section. Many individuals, not reflected in the authorship, 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. We acknowledge and heartily thank 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 experience. 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 our two agencies and helped solve innumerable logistical difficulties.

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

More than 95 percent of the quadrangle is federally owned land, including 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 U.S. 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 Payette River,[2] 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

[1]In this report, the term "Challis quadrangle," unless otherwise noted, refers to the 1°×2° quadrangle and not to the 15-minute quadrangle of the same name.

[2]Wherever it is necessary to use place names in the text, either the name appears on one of the maps or the geographic coordinates to the nearest minute are given. An index map to 7 1/2 and 15-minute quadrangles included within the Challis quadrangle is shown on plate 1.

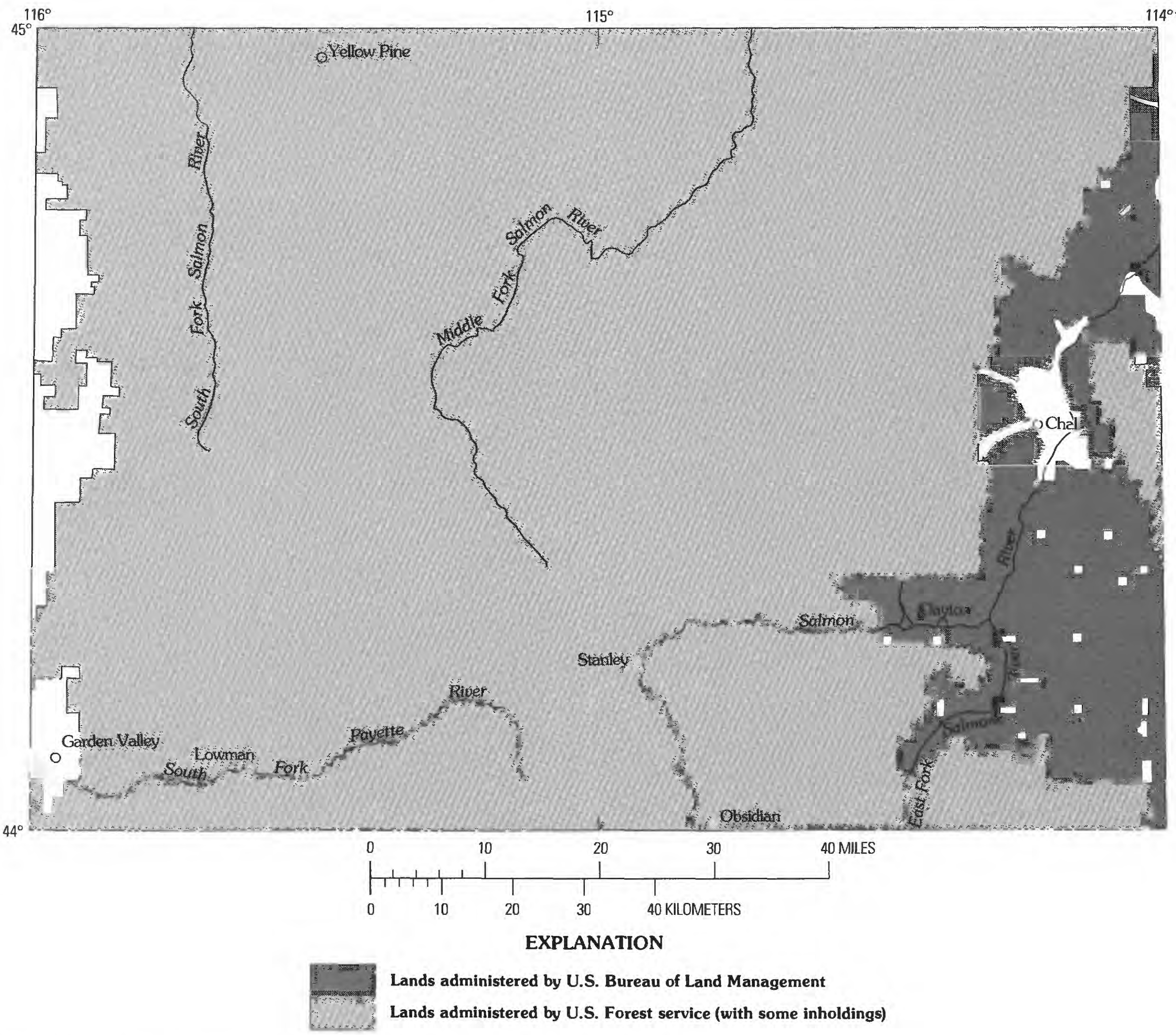


Figure 1. Principal geographic features of the Challis 1°×2° quadrangle, Idaho.

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.

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

GEOLOGIC SETTING AND HISTORY OF MINERALIZATION

By Frederick S. Fisher

Five main groups of rocks are present in the Challis quadrangle (fig. 2). Middle Proterozoic sedimentary and metamorphic rocks crop out in the northern and eastern parts of the quadrangle. Paleozoic sedimentary rocks are mostly in the south-central and eastern parts, and outcrops are scattered 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

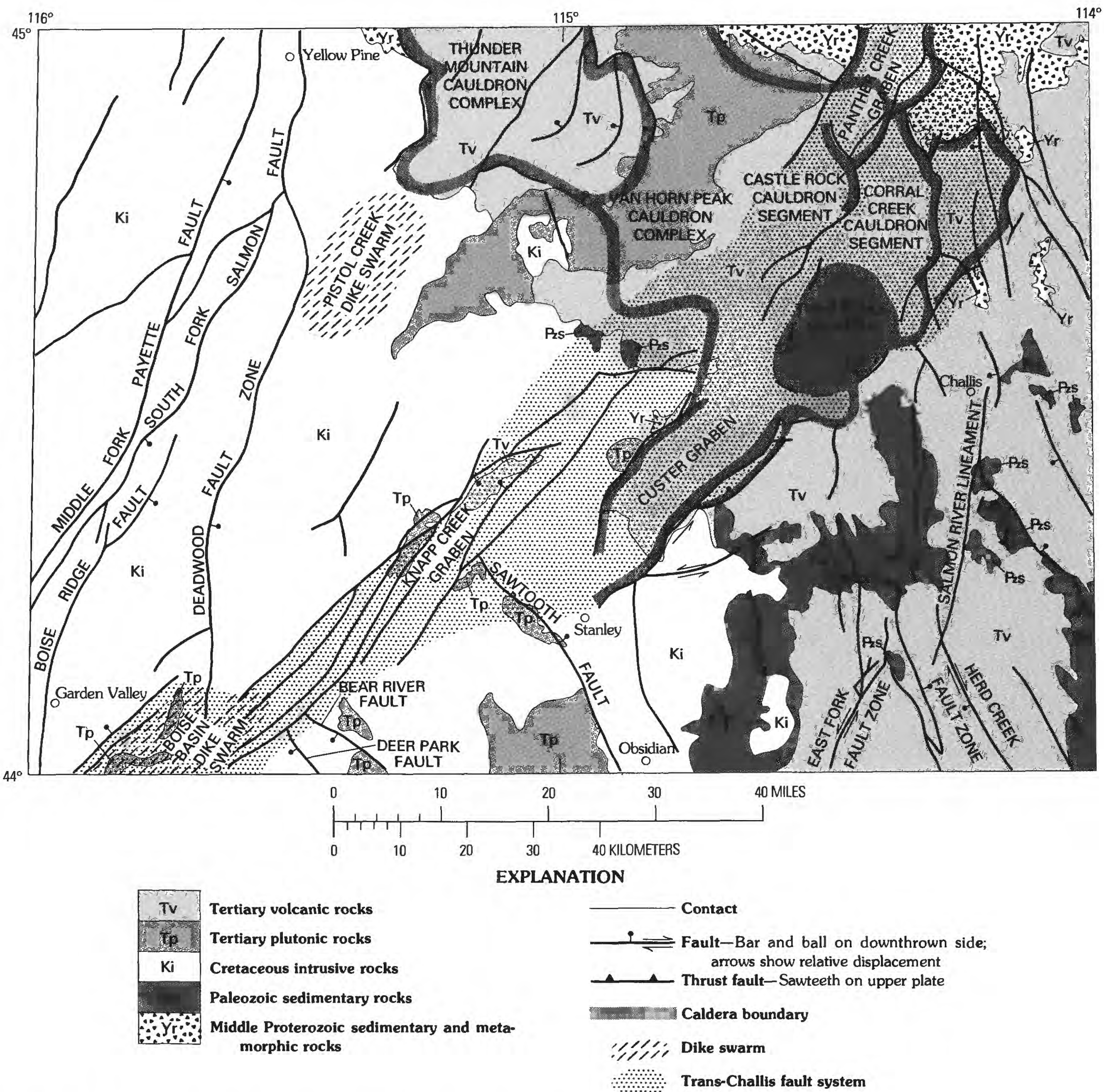


Figure 2. Principal geologic features of the Challis 1°×2° quadrangle, Idaho.

eastern half of the quadrangle. Tertiary batholiths and stocks are widespread in the central part.

Four major structural features characterize the Challis quadrangle (fig. 2): the trans-Challis fault system of northeast-striking high-angle faults, fracture systems, dike swarms, and grabens; a north- and northwest-striking system of high-angle faults; caldera and collapse features associated with the Challis volcanic field; and numerous thrust faults in the Paleozoic rocks.

The earliest metallogenic event was concentration of base and precious metals in the Proterozoic. Nearly 1 b.y. 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, 1983). Later Proterozoic igneous activity consisted of intrusion of granitoid plutons about 1.5–1.3 b.y. ago (Evans and Zartman, 1981). Hughes (1983) suggested that the argillaceous rocks of the Yellowjacket Formation were deposited in a rift basin bordering the craton and that they represent depositional environments ranging from basinal to deep-water clastic fan deposits and turbidites. Metals concentrated in the Yellowjacket Formation are cobalt, copper, and iron, lesser amounts of gold, and probably some silver and lead. The metals are stratabound and were probably introduced syngenetically with the enclosing sediments by some type of sea-floor hot-spring system related to the mafic volcanic activity (Hughes, 1983).

Rocks of the Yellowjacket Formation and Hoodoo Quartzite were complexly folded and metamorphosed to greenschist facies probably between 1.4 and 1.2 b.y. ago (Hughes, 1983). 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 Proterozoic deposits.

During the Paleozoic Era, silver, barium, lead, vanadium, and zinc were deposited syngenetically with many types of sediments (Skipp and others, 1979; Fisher and May, 1983; 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. 23), 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 folded and thrust eastward over a wide area (Dover, 1980). Presumably, some refolding of the Proterozoic 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 of the Grand Prize and Dollarhide Formations have potential for deposits of zinc, lead, and barite (Hall and Hobbs, this volume, p. 25; 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 possible that the metals in these deposits were derived from metalliferous Paleozoic and Proterozoic rocks by hydrothermal systems associated with the various intrusive phases of the batholith; the batholith itself contributed little metal 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 they accumulated in placer deposits as a result of late Tertiary weathering followed by stream winnowing during the Pleistocene and Holocene (Schmidt and Mackin, 1970).

Tertiary time was characterized by deposition of the Eocene Challis Volcanic Group, development of the Challis volcanic field, and emplacement of several batholiths and many stocks (fig. 2). Prior to the igneous activity, however, the Idaho batholith was eroded, and arkosic sediments were deposited locally. These sediments eventually were the traps for 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 5–6 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; the Van Horn Peak cauldron complex formed first and was closely followed by (and probably was partly concurrent with) the formation of the Custer graben and of the Thunder Mountain and Twin Peaks calderas (Fisher and Johnson, this volume, p. 41). The size and shape of the calderas were closely related to pre-existing graben-bounding, northeast-striking faults. Northeast- and northwest-striking high-angle faults began to form at least 51 m.y. ago, as dated by lava 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. 41). 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. 44).

A great diversity of deposits is associated with Tertiary igneous activity (pl. 1, table 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 m.y. A broad paragenetic sequence of three stages can be postulated for Tertiary mineral deposits in the Challis quadrangle: (1) deposition of base and precious metals, overlapped and followed by (2) deposition of fluorite and possibly mercury minerals, in turn overlapped and followed by (3) zeolite development. This sequence is not tightly defined 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 (1) the lead-silver-antimony-tin veins in the Wood River Formation in the southern part of the quadrangle; (2) tungsten-antimony-gold deposits at Yellow Pine; (3) stratabound and vein uranium deposits near Stanley; (4) vein fluorspar deposits near Meyers Cove, Challis, and Stanley; (5) mercury vein-replacement deposits in roof pendants near Yellow Pine; and (6) 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 did the Idaho batholith) simply provide a driving mechanism for convecting hydrothermal systems, or were the plutons themselves metalliferous? Geochemical evidence suggests that the Tertiary granite was 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

By Frederick S. Fisher

Eight geologic terranes have been identified in the Challis quadrangle: the Proterozoic, carbonate, black shale, Idaho batholith, Challis volcanic, Eocene plutonic, alluvial, 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 faults, grabens, calderas, aligned plutons, and dike swarms. Each of the terranes contains distinctive ore deposits and also some ore deposits that are present in other terranes. Each terrane has had a characteristic history of mineralization, but commonly metals introduced in one terrane were remobilized and form important ore deposits in other terranes. For example, metals introduced syngenetically in the black shale terrane were remobilized by igneous activity associated with the emplacement of the Idaho batholith and also Tertiary plutons and were 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 criteria for recognizing 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, 1992, in pocket); for detailed information the reader is referred to that publication. Table 1 lists the types of known ore deposits in each terrane.

Table 2 shows the geochemistry of the known types of ore deposits that are listed in table 1. Of the 30 elements listed in table 2, 20 are present in one or more of the different types of deposits as ore metals 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 many types of deposits and is a useful pathfinder element for base- and precious-metal veins, deposits associated with rhyolite emplaced near the surface, polymetallic skarn, and most of the replacement and stratabound syngenetic deposits. Antimony is also common and may be used as a pathfinder for most of the vein deposits and several of the irregular and stratiform replacement deposits.

Table 1. Types of ore deposits and host geologic terranes in the Challis 1°×2° quadrangle, Idaho.

[See end of table for explanation of symbols]

	Terrane							
	Proterozoic terrane	Carbonate terrane	Black shale terrane	Idaho batholith terrane	Challis volcanic terrane	Eocene plutonic terrane	Alluvial terrane	Trans-Challis fault system terrane
KNOWN TYPES OF ORE DEPOSITS								
Veins:								
Precious metals	◒	--	--	◒	●	●	--	●
Mixed base and precious metals	O	◒	◒	●	--	--	--	O
Lead-silver-zinc-antimony-tin	--	--	●	--	--	--	--	--
Fluorspar	--	◒	--	●	●	●	--	●
Uranium	--	--	--	◒	--	O	--	--
Tungsten	O	--	--	●	--	--	--	--
Manganese	--	--	--	--	--	O	--	--
Semiprecious opal	--	--	--	--	O	--	--	--
Stockworks:								
Cretaceous molybdenum	--	--	●	●	--	--	--	--
Tertiary molybdenum	--	--	--	--	--	●	--	--
High-level, rhyolite-hosted precious metals	--	--	--	--	●	--	--	●
Disseminations:								
Graphite in metamorphic rocks	O	--	--	O	--	--	--	--
Pegmatites:								
Mica, feldspar, columbite, and rare-mineral pegmatites	--	--	--	●	--	--	--	--
Piezoelectric quartz crystal-bearing pegmatites	--	--	--	●	--	--	--	--
Miarolitic cavities:								
Semiprecious gemstone	--	--	--	--	--	●	--	--
Skarns:								
Polymetallic	●	--	●	●	--	--	--	--
Replacement deposits:								
Rare-earth elements	O	--	--	O	--	--	--	--
Base and precious metals	--	●	--	--	--	--	--	--
Mercury	◒	--	--	--	--	--	--	--
Zeolites in tuffaceous rocks	--	--	--	--	◒	--	--	--
Stratiform:								
Precious metals in epiclastic sediments	--	--	--	--	●	--	--	--
Precious metals in volcanic tuffs	--	--	--	--	●	--	--	--
Fluorspar in carbonate rocks	--	●	--	--	--	--	--	--
Barite	--	--	◒	--	--	--	--	--
Uranium in sedimentary rocks	--	--	--	--	O	--	--	--
Stratabound syngenetic:								
Vanadium	--	--	◒	--	--	--	--	--
Precious and base metals in argillite and micritic limestone	--	--	●	--	--	--	--	--
Cobalt-copper deposits	●	--	--	--	--	--	--	--
Placers:								
Gold	--	--	--	--	--	--	●	--
Radioactive black sand	--	--	--	--	--	--	●	--

Table 1. Types of ore deposits and host geologic terranes in the Challis 1°×2° quadrangle, Idaho—Continued.

	Terrane							
	Proterozoic terrane	Carbonate terrane	Black shale terrane	Idaho batholith terrane	Challis volcanic terrane	Eocene plutonic terrane	Alluvial terrane	Trans-Challis fault system terrane
Rock products:								
Quartzite (flagstone)	--	●	--	--	--	--	--	--
Granite (building stone)	--	--	--	●	--	--	--	--
Volcanic tuff (building stone)	--	--	--	--	●	--	--	--
Sand and gravel	--	--	--	--	--	--	●	--
POSTULATED TYPES OF ORE DEPOSITS								
Opalite-type mercury veins	--	--	--	--	X	--	--	--
Uranium in sedimentary rocks in contact zones with granitic rocks	X	X	X	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 Proterozoic 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:

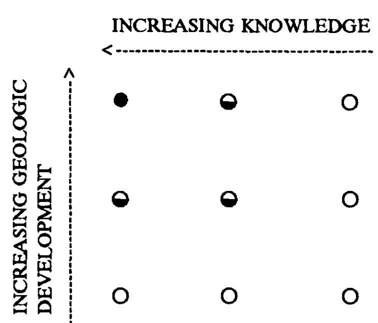


Table 2. Geochemistry of types of ore deposits known to exist in the Challis 1°×2° quadrangle, Idaho.

[●, ore; ○ possible byproduct; •, geochemically anomalous; —, not anomalous or not detected]

	Ag	As	Au	Ba	Be	Bi	Cd	Co	Cr	Cu	F	Hg	Mn	Mo	Nb	Ni	Pb	REE[1]	Sb	Se	Sn	Ta	Te	Th	Ti	U	V	W	Zn	Zr
Veins:																														
Precious metals	●	•	●	—	—	•	—	—	—	○	•	•	—	—	—	—	○	—	•	—	—	—	—	—	—	—	—	—	○	—
Mixed base and precious metals	○	—	○	•	—	—	—	—	—	●	•	—	—	—	—	—	●	—	•	—	—	—	—	—	—	—	—	—	●	—
Lead-silver-zinc-antimony-tin	●	•	○	—	—	•	•	—	—	●	—	—	—	—	—	—	●	—	○	—	○	—	•	—	—	—	—	—	●	—
Fluorspar	•	—	○	•	—	—	—	—	—	—	●	—	—	•	—	—	—	—	•	—	•	—	—	—	—	—	—	—	—	—
Uranium	○	•	○	—	—	—	—	—	—	•	•	—	—	•	—	—	•	—	•	—	—	—	—	—	—	●	—	—	•	—
Tungsten	○	•	○	—	—	—	—	—	—	—	—	—	—	—	—	—	•	—	●	—	—	—	—	—	—	—	—	●	•	—
Manganese	—	—	—	—	—	—	—	—	—	—	—	—	○	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Semiprecious opal	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Stockworks:																														
Cretaceous molybdenum	●	—	•	—	—	—	—	—	—	○	—	—	—	●	—	—	○	—	—	—	—	—	—	—	—	—	—	○	•	—
Tertiary molybdenum	•	—	—	—	—	—	—	—	—	●	—	—	—	●	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
High-level, rhyolite-hosted precious metals	●	•	●	—	•	—	—	—	—	—	•	—	—	•	—	—	—	—	—	•	—	—	—	—	—	—	—	—	—	•
Disseminations:																														
Graphite in metamorphic rocks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pegmatites:																														
Mica, feldspar, columbite, and rare-mineral pegmatites	—	—	—	—	○	—	—	—	—	—	—	—	•	—	○	—	—	•	—	—	—	○	—	—	—	—	—	—	—	—
Piezoelectric quartz crystal-bearing pegmatites	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Miarolitic cavities:																														
Semiprecious gemstone	—	—	—	—	○	—	—	—	—	—	•	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Skarns:																														
Polymetallic	●	•	○	—	—	•	—	—	—	●	—	—	—	•	—	—	●	—	—	—	—	—	—	—	—	—	—	●	●	—
Replacement deposits:																														
Rare-earth elements	—	•	—	•	—	—	—	—	—	—	—	•	•	—	—	—	—	○	—	—	—	—	—	—	—	—	—	—	—	•
Base and precious metals	●	•	•	—	—	—	—	—	—	●	•	—	—	—	—	—	●	—	•	—	—	—	—	—	—	—	—	—	●	—
Mercury	—	•	—	—	—	—	—	—	—	—	—	●	—	—	—	—	—	—	•	—	—	—	—	—	—	—	—	—	—	—
Zeolites in tuffaceous rocks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Stratiform:																														
Precious metals in epiclastic sediments	●	•	●	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	•	—	—	—	—	—	—	—	—	—	—	—
Precious metals in volcanic tuffs	●	•	●	—	—	—	—	—	—	•	—	—	—	•	—	—	—	—	•	—	—	—	—	—	—	—	—	•	•	—
Fluorspar in carbonate rocks	—	•	—	•	—	—	—	—	—	•	●	—	—	—	—	—	•	—	—	—	—	—	—	—	—	—	—	—	•	—
Barite	—	—	—	●	—	—	—	—	—	—	—	—	—	•	—	—	—	—	—	—	—	—	—	—	—	—	—	—	•	—
Uranium in sedimentary rocks	—	•	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	•	—	—	—	—	—	—	●	—	—	—	—

	Ag	As	Au	Ba	Be	Bi	Cd	Co	Cr	Cu	F	Hg	Mn	Mo	Nb	Ni	Pb	REE[1]	Sb	Se	Sn	Ta	Te	Th	Ti	U	V	W	Zn	Zr
Stratabound syngenetic:																														
Vanadium	○	•	--	○	--	--	--	--	•	--	--	--	--	•	--	•	○	--	--	•	--	--	--	--	--	--	●	--	○	--
Precious and base metals in argillite and micritic limestone	○	•	--	•	--	--	--	--	--	--	--	--	--	--	--	--	●	--	--	--	--	--	--	--	--	--	--	--	●	--
Cobalt-copper deposits	--	•	○	--	--	•	--	●	--	●	--	--	--	--	--	•	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Placers:																														
Gold	●	--	●	--	--	--	--	--	--	--	--	•	--	--	○	--	--	○	•	--	--	○	--	○	--	○	--	--	--	--
Radioactive black sand	○	--	○	--	--	--	--	--	--	--	--	--	--	--	○	--	--	○	--	--	--	●	--	●	--	●	--	--	--	--

[1]Rare-earth elements.

PROTEROZOIC 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. 2; pl. 2). Roof pendants of possible Proterozoic or Paleozoic metasedimentary rocks in the Idaho batholith have been mapped in the central part of the quadrangle, and there are several clusters of small pendants 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 summarizes the essential features of each of the units but must rely heavily on exposures outside the quadrangle for those units that are represented by abbreviated sections within the quadrangle.

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. He 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 principal reference section, 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 Yellowjacket district have been identified as part of the Yellowjacket sequence. These exposures are separated from rocks in the Yellowjacket district by intrusive rocks of Cretaceous and Tertiary age or by a thick cover of rocks belonging to the Eocene Challis Volcanic Group. The exposures are notably different in composition, sequence, thickness, and degree of metamorphism from rocks elsewhere in the Yellowjacket sequence. Because of these differences, and the wide separation in location, they will be described separately.

The Yellowjacket exposures in the vicinity of Iron Creek (44°55′ N., 114°05′ W.) and Panther Creek, in the northeastern part of the quadrangle, are part of an extensive area of Yellowjacket Formation studied by Lopez (1981). Lopez described 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 identified. Much of the section is well laminated, having graded bedding in both laminae and beds, and it 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 in the Yellowjacket were identified by Lopez (1981). Three of these are well exposed in the Challis quadrangle; the other two are best exposed just north of the quadrangle. Figure 3 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.—This unit consists of graded beds 4–36 in. thick of coarse- to medium-grained quartzite that grades upward into very fine grained 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.—This unit is predominantly very fine grained argillaceous quartzite and siltite. Graded beds are 2–20 in. thick. Characteristic of this member are beds and lenses of calcareous quartzite. It is about 5,300 ft thick.

Member C.—This unit is 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.—This unit is predominantly very fine grained argillaceous quartzite in graded beds 4–36 in. thick. The member is at least 8,200 ft thick but may be as much as 11,500 ft.

Member E.—This unit comprises quartzites having 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°×2°

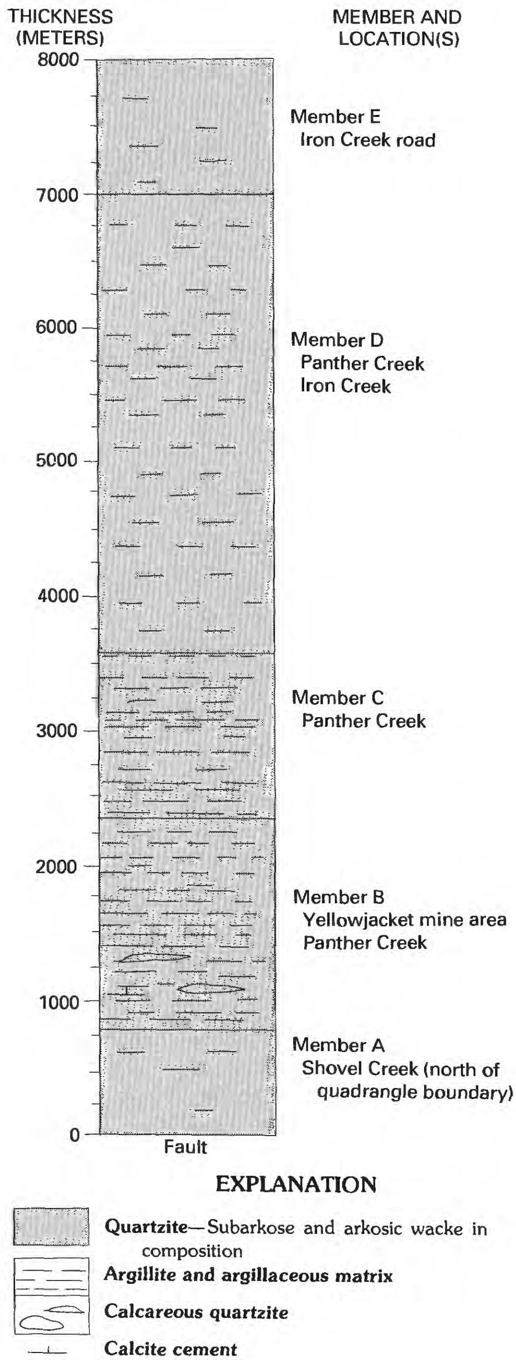


Figure 3. Composite stratigraphic column of the Yellowjacket Formation, showing areas where each member was studied, Challis 1°×2° quadrangle, Idaho.

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. There are several occurrences of Blackbird-type mineralization in the Yellowjacket on Iron Creek (Modreski, 1985).

Extensive exposures of sedimentary and volcanic rocks of heterogeneous composition occur about 40 mi west of 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 been assigned to the Yellowjacket by B.F. Leonard (written commun., 1985) on the basis of extensive detailed work in these general areas. According to Leonard's description,

> 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.

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.), about 2.5 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 principal reference section (T. 18 N., R. 17 E.) and a few other places depositional top and bottom contacts have been identified (Ekren, 1985). Ross (1934b) noted that the Hoodoo is definitely younger than the Yellowjacket, which it appears to overlie 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 (1988) considered that both the basal and upper contacts of the Hoodoo are transitional into the Yellowjacket below and into a series of unnamed argillaceous quartzite beds above that are of Yellowjacket affinity, and may be as much as 3,300 ft thick. In the Yellowjacket Mountains these unnamed beds (unit Yaq) have been mapped as separate from the Yellowjacket Formation by Ekren (1988, pl. 1), who considered the Hoodoo to be gradational with the Yellowjacket and with the unnamed quartzite. 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 having light-brown joint surfaces that are stained with limonite. In a very few places the rocks are light yellow gray, dark gray, and even black where metamorphic biotite and amphibole have developed from argillaceous impurities, which are more prevalent in the basal part of the unit. Most of the rock contains 85–90 percent quartz in grains that range in diameter from 0.2 to 1.5 mm but are mostly less than 1 mm. Feldspar, mostly microcline and orthoclase, but with various 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.

Along Hoodoo Creek, the Hoodoo Quartzite 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, 1988), 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, 1992, in pocket). These strata are a small sample of 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 the rock is 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, but considerable thin bedding is 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, 1992, in pocket). This unit was first named the Apple Creek Phyllite by Anderson (1961) and redefined as the Apple Creek Formation by Ruppel (1975) in its principal reference section in the Patterson quadrangle, Lemhi County. Both Lopez (1981) and Ekren (1988) recognized these strata as allochthonous in the Challis quadrangle and thrust over the Yellowjacket from the west (Lopez, 1981; Ruppel and Lopez, 1988), probably on the Medicine Lodge thrust system (Ruppel, 1978). Their correlation with the Apple Creek in the Patterson quadrangle 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 crosslaminated 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 in the Challis quadrangle assigned to the Apple Creek. Although many features of the Apple Creek Formation are similar to those of parts of the Yellowjacket, the basic evidence favors correlation with the Apple Creek Formation.

GUNSIGHT FORMATION

There are three small areas of strata that are tentatively assigned to the Gunsight Formation in the northeast corner of the quadrangle, where they are bounded by steep faults and are in contact with the Yellowjacket, Apple Creek, or Big Creek Formations, or with the Challis Volcanic Group; in a few places the 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 crosslaminated. 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 crosslaminae. Much of the Gunsight is dirtier than the Big Creek Formation, which 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 4–5 mi 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 crosslaminated; 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 locality is in the southwestern part of the May 15-minute quadrangle, adjacent to and east of the Challis 15-minute quadrangle, there are other occurrences 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 that 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: (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 crosslaminated, light-pinkish-purple quartzite that are identical to the predominant rock type of the Swauger Formation. Many of the fine-grained, platy, impure quartzite beds are highly feldspathic and have maroon argillite films on the bedding planes, micaceous partings, and mud-chip breccias that were 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, the unit containing a few widely spaced, crosslaminated, 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. There are several beds, 3–10 ft thick, of a light-gray-green, siliceous mudstone or porcellanite 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 LATE 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 and includes some thick zones that are 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 is 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 the Swauger Formation suggest possible correlation with the Late Proterozoic(?) and early Cambrian Wilbert (Ruppel and Lopez, 1988) 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 (PALEOZOIC(?) OR PROTEROZOIC(?))

Roof pendants in the Idaho batholith, usually of small to medium 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 southeastern 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.

RELATIONSHIP OF MINERAL DEPOSITS TO PROTEROZOIC TERRANE

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. 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 and contains no 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, 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 (Anderson, 1953). These metals occur in a predominantly quartz gangue in veins, irregular lodes, shear zones, stockwork, and breccia filling. The deposits were roughly divided by Anderson into gold–base metal deposits, silver-copper deposits, and silver-lead deposits, but these types showed 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 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 lb of copper, and 17,275 lb of lead was produced. A few properties have had intermittent but relatively small production 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.

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 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 were formed where shear zones 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 TERRANE

By S. Warren Hobbs

Formations in which limestone, dolomite, or both are the predominant 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 Proterozoic 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 and silty carbonate formations and between calcareous and dolomitic sandstone and siltstone is arbitrary in many cases but usually depends on the predominant 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, which includes the major part of the Clayton 15-minute quadrangle, and in the Lone Pine Peak quadrangle to the east (pl. 1; fig. 4). Ten major carbonate formations have been identified in these areas. Ore deposits that have had significant production occur in or near the Bayhorse Dolomite, the Ella Dolomite, and the Saturday Mountain Formation, all of which are present in the structurally complex Bayhorse mining district. The remaining carbonate formations in the Lone Pine Peak quadrangle, separated from those in the Bayhorse district by the Salmon River lineament (fig. 4) (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 is present 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.

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. 4) 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. (oral commun., 1964), and it was 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, gorgelike reach of Bayhorse Creek (44°24′ N., 114°20′W.) that is about 1,500 ft long and 30–35 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 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 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 Early Ordovician and Late Cambrian age. So far as is known, no other comparable sequence of rocks has been recognized in east-central Idaho. The dolomite was mapped with the Garden Creek Phyllite by Fisher and others (1992, in pocket).

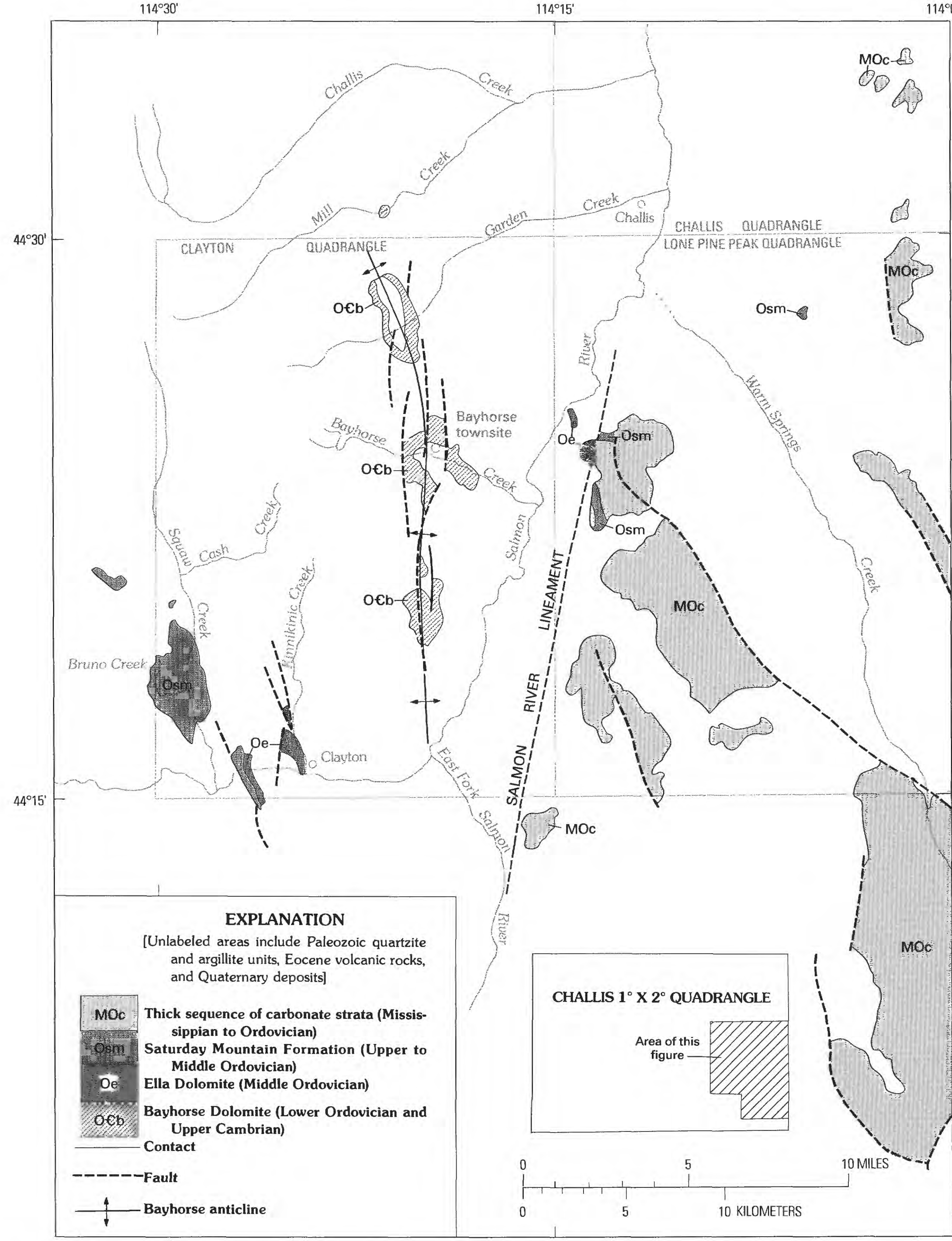


Figure 4. Generalized geology of southeastern part of the Challis 1°×2° quadrangle, Idaho, showing major units of carbonate rock terrane.

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. 4). Near the north end of this structure the Bayhorse Dolomite forms an elongated oval band about 3.5 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 farther 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-striking 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 not knowing the 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, 1991) emphasized the diverse character of the unit, which not only comprises limestone and dolomite, but which 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 upper contact zone, especially where disturbed, brecciated, or weathered on the paleoland 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 farther west, and he reported 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 Late Cambrian because of its position below the Ramshorn Slate, which was then considered to be Early 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 early Paleozoic and most likely Late Cambrian or Early Ordovician.

ELLA DOLOMITE

The name Ella Dolomite, first used in an unpublished thesis by Patton (1948), was formally adopted by Hobbs and others (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 4.

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 1.5 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°14′ N., 114°26′ W.). There are widely spaced outcrops east of, and nearly parallel to, the Salmon River from East Fork 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. It is generally medium to medium-dark gray, commonly having 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, are dark gray, and weather to deep brown. This basal zone is distinctive and has proved useful as a marker bed.

Locally, a 20- to 30-ft zone about 230 ft above the base of the Ella 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 study of 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. 4) and there are 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 at one time 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 fauna that has been identified as late Middle Ordovician (Hobbs and others, 1968). A short distance from the contact the shale and siltstone are slightly calcareous and weather into small plates and chips that are black on fresh surfaces but buff or yellowish gray when weathered. Within several hundred feet, in place of the limy siltstone there is a silty, dark-gray limestone that weathers into buff or light-yellow 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 nearly 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. 4). 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- and medium-gray chert. This part of the section is estimated from map measurement to be about 2,000 ft thick but may be 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, 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. 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 more than 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 rock types 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 Late Ordovician. Some latest Middle Ordovician and Early Silurian may be included. The thinner section of nearly continuous carbonate strata studied by Hays and others (1978) 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

There are two exposures of dolomite, each less than 0.1 sq mi in area, east and west of Squaw Creek about 7 mi north of the Salmon River. One exposure is about 0.5 mi west of a point on Squaw Creek nearly 1 mi south of the mouth of Cash Creek (fig. 4). The other, and larger, is along the north side of Cash Creek about 2 mi above its confluence with Squaw Creek. Although only the eastern outcrop is dated from fossil evidence to be Ordovician, the western outcrop is considered to be correlative with the eastern on the basis of stratigraphic similarities and structural position. This dolomite 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 late 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 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, which has its type locality 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 Formation and overlying unnamed dolomite units, the Jefferson Dolomite, Grand View Dolomite, and Three Forks Formation, all of Devonian age, and the McGowan Creek, Middle Canyon, and Scott Peak Formation of Mississippian age.

RELATIONSHIP OF MINERAL DEPOSITS TO CARBONATE TERRANE

In the carbonate terrane west of the Salmon River lineament, significant replacement ore bodies containing base and precious metals 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 developed are underlain by thick sections of black shale and siltstone. These black argillaceous rocks have been proposed as the source rock for veins and stratabound deposits within the black shale itself (Hall and Hobbs, this volume, p. 31) 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 section east of the lineament is notably barren of the metalliferous mineral deposits that characterize the Bayhorse district to the west. This lack of mineral deposits may result from a combination of such factors as a drastic change in rock type across a structural discontinuity, lack of igneous intrusion, paucity of black shale as source rock, or absence of favorable structures.

BLACK SHALE TERRANE

By Wayne E. Hall and S. Warren Hobbs

The south-central part of the Challis quadrangle is underlain by metalliferous, black, siliceous, clastic sedimentary rocks of Late Cambrian to Permian age. This black shale terrane is approximately 12 mi wide in an east-west direction between Yankee Fork 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. 5). It extends south from the Challis quadrangle 57 mi through the Wood River area to the latitude of Bellevue, Idaho.

The geology and mineral deposits of this belt have been described by Ross (1937a), Hall (1985), Hobbs (1985), Tschanz and others (1986), and Tschanz and Kiilsgaard (1986). 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 lithostratigraphic units can be combined informally as tectono-stratigraphic units having neither 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 to be mapped separately. In this paper the term Wood River Formation can be described as having 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 subterranes separated by a 7-mi-wide belt of Ordovician and Cambrian(?) quartzite and carbonate rock of the carbonate terrane (fig. 5). The Bayhorse district subterrane, on the east, includes the Bayhorse mining district and is composed of lower Paleozoic rocks. The White Cloud Peaks subterrane, on the west, is composed of younger Paleozoic rocks.

BAYHORSE DISTRICT SUBTERRANE

The Bayhorse district is underlain by an allochthonous sequence of undated strata of probable Middle Cambrian and Early Ordovician age. These strata include four formations that constitute the core of the massive Bayhorse anticline that trends across the entire Bayhorse region (figs. 4, 5), 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 more than 5,000 ft thick and comprises, from top to bottom, the Ramshorn Slate, Bayhorse Dolomite, and Garden Creek Phyllite (Ross, 1934a), and the informally named lower dolomite of Bayhorse Creek. Two of these stratigraphic units, the Ordovician Ramshorn Slate and the Middle(?) Cambrian 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 a part of the carbonate rock terrane (fig. 4).

GARDEN CREEK PHYLLITE

The Garden Creek Phyllite, named by Ross (1934a), underlies the Bayhorse Dolomite and is exposed for 2.5 sq mi 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 that has abundant silvery sericite on cleavage surfaces. Some of the phyllite is slightly calcareous. The rock is soft and weathers so readily that exposures are rare.

Most of the argillite beds are 1–15 mm thick, and the grain size ranges from clay to silt. Interbeds of fine sand as much as 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 shale, 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 the absence of fossil remains in the rock.

Bedding, where it can be identified, is in many places intensely crumpled, and the axes of small folds plunge variously 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 development of

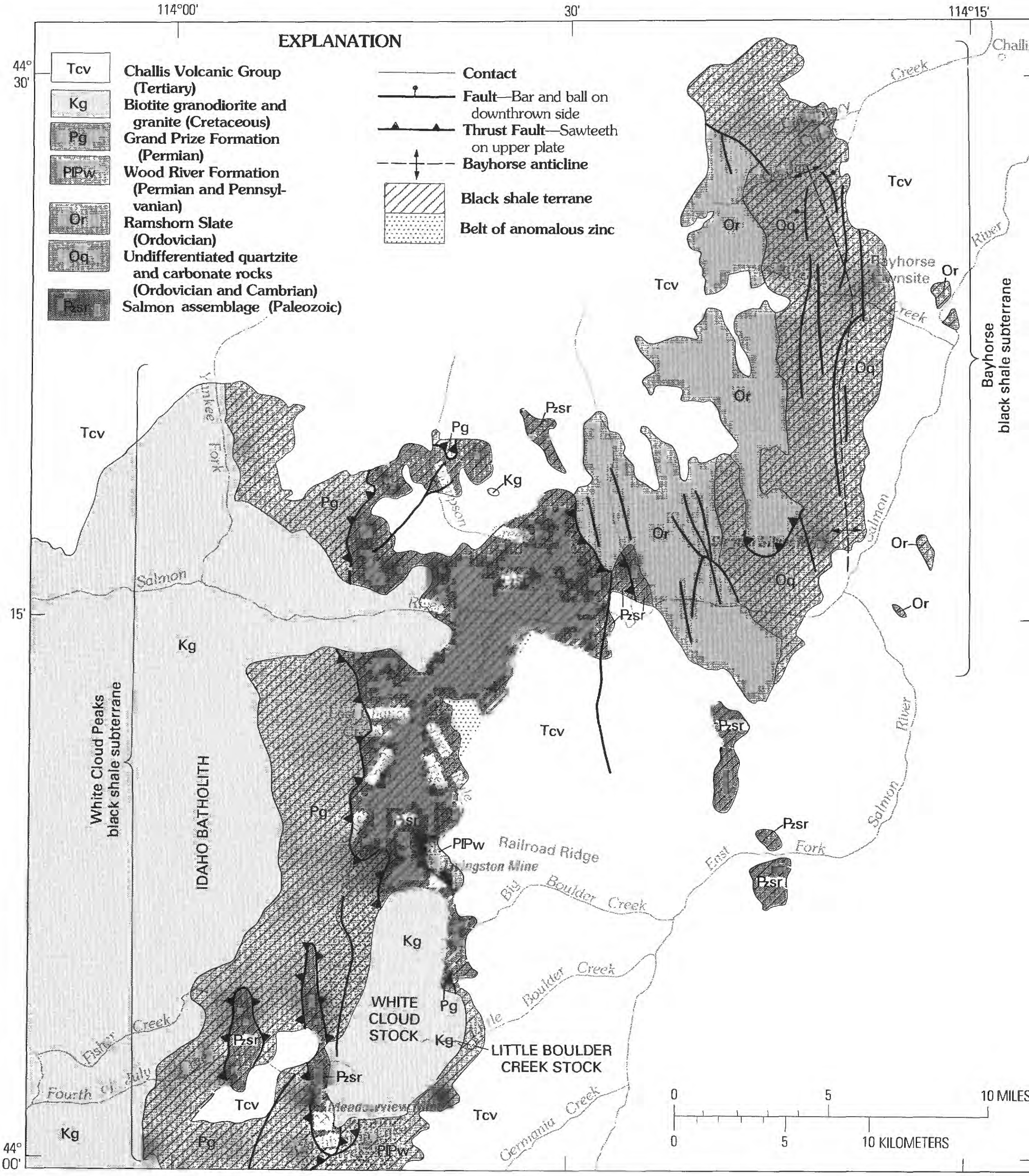


Figure 5. Geology of central Idaho black shale terrane in the Challis 1°×2° quadrangle, Idaho.

axial plane cleavage of an incompetent, thick, argillaceous unit that has been folded between competent carbonate sequences.

An estimated 1,200–1,400 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.

RAMSHORN SLATE AND ITS BASAL CONGLOMERATE

The 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 the Challis Volcanic Group for an unknown distance, and on the east by a contact roughly parallel with the volcanic rocks (fig. 5). 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 overlies an erosional surface that 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, and dark colored on fresh fracture (generally in shades of gray, green, or purplish gray). They 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 seems to become gradually less intense 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, there is a locally developed belt of thick basal conglomerate that strikes west-northwest 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 main mass of the Ramshorn was deposited. To the north and south, the conglomerate interfingers with fine sandstone and siltstone that are part of the lower Ramshorn rocks. 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, the east limb being nearly vertical and the west limb faulted and irregularly dipping. 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, have local drag folds, and are 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.

WHITE CLOUD PEAKS SUBTERRANE

The White Cloud Peaks subterrane is an area of about 150 sq mi in the south-central part of the Challis quadrangle along the east side of the Idaho batholith (fig. 5). It continues south into the Hailey 1°×2° quadrangle for 60 mi. On the north it is covered by the 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 subterrane are the Salmon River assemblage, Wood River Formation, and Grand Prize Formation (fig. 5).

SALMON RIVER ASSEMBLAGE

The Salmon River assemblage is the structurally lowermost allochthon exposed in the White Cloud Peaks subterrane (fig. 5). 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. 5). The upper contact is a thrust fault overlain by the Wood River allochthon on the southeast and the Grand Prize allochthon on the west (fig. 5). 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 (1986). 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. The lower part of the sequence contains thin beds of highly carbonaceous micritic limestone. Fine-grained pyrite, pyrrhotite, and (locally) sphalerite are disseminated in the carbonaceous argillite and micritic limestone. Bedding thickness ranges mostly between 2 and 18 in., and sedimentary textures and structures include graded beds, local crossbeds, laminations, scour, sole markings, and local convolute structures produced by syndepositional slumping. The less competent beds, the argillite and calcareous siltstone, 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 because the breccia is commonly silicified and is very resistant to erosion. The breccia formed where quartzite is interbedded with incompetent carbonaceous limestone, apparently 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 underwent 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, semirounded 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-minute quadrangle (pl. 1). This material (USGS location 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 (Hobbs and others, 1991).

A second faunal locality, located in the lower part of Mill Creek near the northern edge of the Livingston Creek 7½-minute quadrangle (pl. 1), comprises a large, angular float block that contains an abundant megafauna (USGS location 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 7½-minute quadrangle (pl. 1). The first locality (USGS location No. 11020–SD), 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 0.5 mi south of the first and on the same side of Thompson Creek, includes three samples, two of which were collected by F.G. Poole and W.E. Hall (USGS location Nos. 9851–CO and 9852–CO), and the third by S.W. Hobbs (USGS location 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 location Nos. 10736–SD and 10737–SD) and examined by A.G. Harris, who reported them to be Middle Devonian. The remaining two known localities are in the lower valleys of Sheephead Creek (44°12′ N., 114°36′ W.) and Last Chance Creek (44°12′ N., 114°37′ W.), which are west-side tributaries to Slate Creek at approximately 4 and 5 mi, 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 F.G. Poole and W.E. Hall (USGS location No. 11021–SD) from detrital limestone float blocks on the north side of the valley and less than 0.5 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 was reported by J.E. 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" inappropriate for these strata. 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 (1992, in pocket) have assigned a Paleozoic age to the entire assemblage.

WOOD RIVER FORMATION

The Middle Pennsylvanian to Early Permian (Leonardian) Wood River Formation crops out over an area of about 8 sq mi 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. 5). The formation extends south of the Challis quadrangle throughout the Wood River Valley region. The Wood River Formation was 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 1–4. 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. These characteristics correlate well with those of units 2, 3, and 4 of the Wood River Formation of the section 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 suggest 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 was metamorphosed by emplacement of the stock to a dense green siliceous calc-silicate rock that is the host rock for molybdenite and scheelite. Identification of some poorly preserved fusulinids verified the field assignment to unit 6. Four collections of fusulinids were taken 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) stated that these samples contain specimens of *Triticites* sp. and *Schwagerina* sp. and confirmed the assignment to unit 6. They represent the upper part of unit 6 (Wolfcampian) of Early Permian age.

GRAND PRIZE FORMATION

The Grand Prize Formation was named by Hall (1985) for a thick sequence of medium- to dark-gray siltite and 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 structurally highest formation in the tectonostratigraphic sequence in the central Idaho black shale belt. It is divided into four informal units that total 4,757 ft in thickness (Hall, 1985). The lower unit is gray, sandy limestone showing abundant crossbedding and convolute structures overlain by dark-gray siltite and limy siltite in the upper part. The next higher 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 considered Early Permian (Leonardian) on the basis of conodont identifications by B.R. Wardlaw and A.G. Harris reported in Hall (1985). However, the Grand Prize could be as old as Pennsylvanian or Early Permian.

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. The rocks were folded prior to or during early stages of thrusting as indicated by truncation of many steep isoclinal folds 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, on the north slope of Washington Basin (44°01′ N., 114°39′ W.), and continuing to the north into the Fourth of July Creek drainage basin (44°03′ N., 114°39′ W.). This tectonic breccia in the Boulder Mountains is the unit that was described by Thomasson (1959) and by Hall and others (1974) as the Hailey Conglomerate Member of the Wood River Formation of Middle Pennsylvanian age. It is now known that the Hailey Conglomerate Member and the tectonic breccia are separate and distinct units. However, the breccia differs in lithology, structural setting, and age from the type Hailey Conglomerate Member. The breccia lies within a regional thrust fault zone between the Salmon River assemblage and the overlying 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 Member. It was formed when the Grand Prize allochthon was thrust to the east upward and over a topographic high caused by the underlying Salmon River allochthon. Many small Cretaceous and Tertiary granitic plutons intruded laterally along this tectonic breccia zone. While doing so, they bleached and metamorphosed by contact the breccia and locally formed mineral deposits within the breccia zone or in steep faults below it.

RELATIONSHIP OF MINERAL DEPOSITS TO BLACK SHALE TERRANE

The black shale terrane 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. 5).

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 Ordovician age and the Salmon River assemblage of Paleozoic age. All of the vein deposits are within 4 mi of Cretaceous granitic plutons.

Copper-lead-silver replacement veins having siderite gangue are present in the Bayhorse district, in the black shale of both the Ramshorn Slate and the Garden Creek Phyllite. The Ramshorn and Skylark mines are two formerly productive mines 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 in the deposits are sphalerite, chalcopyrite, pyrite, and arsenopyrite. The ore is present in shoots within a shear or lode system. Some shoots were mined 300–400 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 with the black shale in the Bayhorse district have a mineralogy different from the deposits 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 subterrane) contains lead-silver-zinc veins with byproduct tin, antimony, and, locally, gold. The Livingston mine (fig. 5) 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 is quartz, calcite, and jasperoid. Jamesonite-bearing veins containing silver, antimony, and small amounts of tin are present in the deposits in the Silver Rule Creek area (44°11′ N., 14°35′ W.), Strawberry Basin (44°04′N. 114°39′ W.), the Fourth of July Creek area (44°03′N., 114°39′ W.), at the Livingston mine, and at the Crater mine at the head of Livingston Creek. These veins are unique to the deposits in the Salmon River assemblage. A belt of lead-silver vein deposits containing tin and antimony extends south of the Challis quadrangle in the Wood River Formation and includes 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 in which tin is anomalous extends for a distance of approximately 30 mi in a north-south direction from Boulder Basin on the south to the areas of the Livingston and Silver Rule mines. 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 in the black shale terrane are localized close to contacts with granitic stocks of Cretaceous age or Eocene felsic stocks and dikes, and underlie regional thrust faults (Hall and others, 1978). Studies of fluid inclusions and stable isotopes in 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 contains predominantly remobilized sphalerite but also pyrite, pyrrhotite, arsenopyrite, and silver-bearing galena. The mine was developed for small, 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). The mine also contains sphalerite-rich stratiform ore of unknown extent. The argillite host rock was shattered at the intersection of the felsic dike and the Livingston vein, and the shattered host rock contains 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. Figure 6*A* 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 6*B* is a photograph of a specimen of ore from 25 ft horizontally into the stope near the contact with the felsic 40- to 60-ft-thick Scotch dike. Some of the galena, jamesonite, and pyrite recrystallized into blebs as much as 0.2–1 mm in diameter and form veinlets that cut across bedding. Figure 6*C* is a photograph of remobilized ore from the center of the stope.

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. 5). It was developed for gold, but also has produced some lead and silver (Ross, 1937a). In the northwest corner of the Livingston Creek 7½-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 concentrated are silver, barium, copper, molybdenum, vanadium, and zinc. Figure 7 shows the range in metals anomalously concentrated in the Salmon River assemblage, the threshold values for anomalously high concentrations as selected from histograms published by Vine and Tourtelot (1970), and the percent of samples having anomalously high concentrations. The analyses show that highly carbonaceous bands in the Salmon

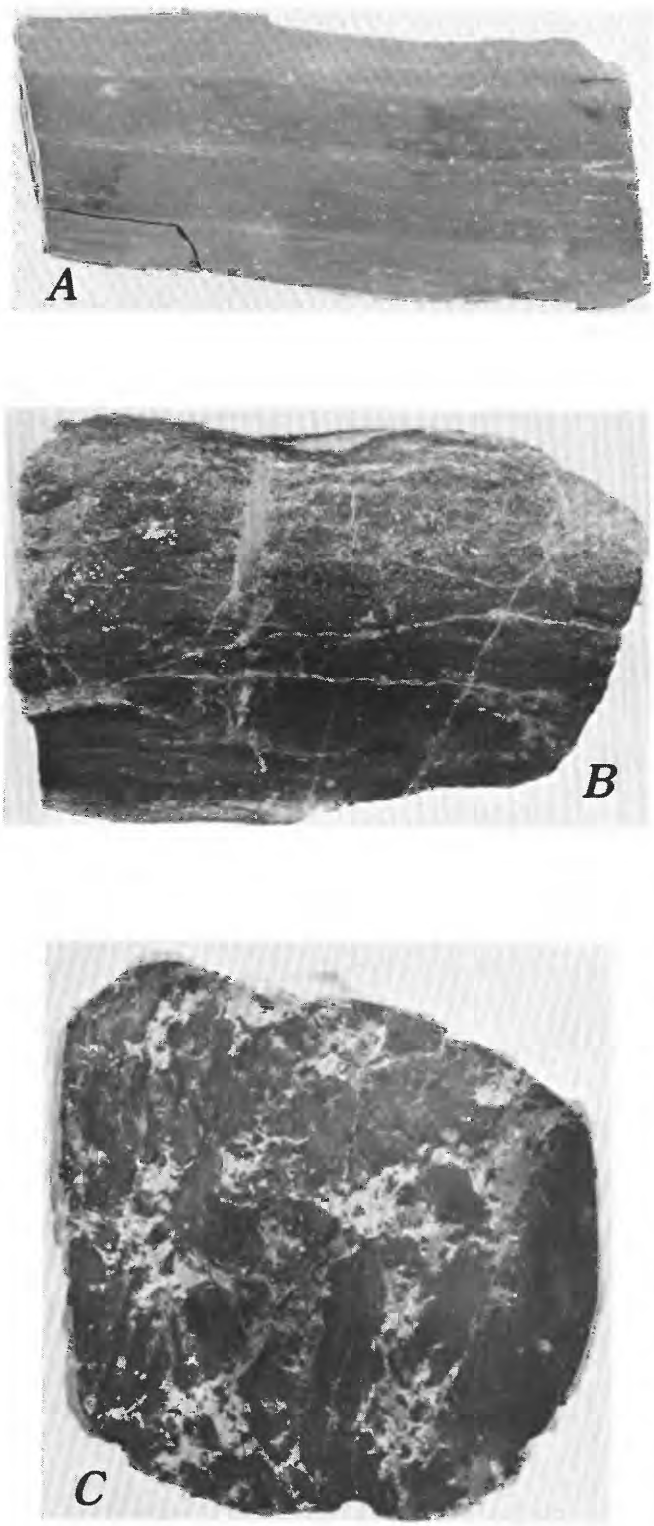


Figure 6. Ore from the Livingston vein. *A*, Stratiform zinc ore; bedded sphalerite and pyrite from margin of Christmas stope. Sample is 4.5 in. long. *B*, Remobilized jamesonite in veinlets and discrete veins. Sample is 3 in. long. *C*, Jamesonite ore containing clasts of bedded ore. Sample is 4×4 in.

River assemblage contained as much as 10,000 ppm vanadium; the assemblage may be of interest as a future source for vanadium.

Zinc is concentrated in the Salmon River assemblage in a belt 20 mi long and 3 mi wide that strikes N. 10° E. in the area of Slate and Mill Creeks (fig. 5) (Tschanz and Kiilsgaard, 1986). Stream-sediment samples collected within this belt contained 100–3,000 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 ore body that was drilled under the U.S. Department of Defense Minerals Economic Assistance (DMEA) program in 1952 (T.H. 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 cadmium-zinc ratio of 1:108 (Van Noy and others, 1986, p. 264).

In Washington Basin (44°01′ N., 114°39′ W.), one northwest-striking and four large northeast-striking quartz-rich stratabound veins that contain disseminated iron sulfides, sphalerite, scheelite, and some gold were developed in the late 19th century for their gold content. 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 2,000 ft (Van Noy and others, 1986). These veins are adjacent or in close proximity to Cretaceous biotite granodiorite plutons. They are interpreted to be stratiform syngenetic deposits that were recrystallized and remobilized by the granodiorite plutons. Blebs, veinlets, and small shoots of jamesonite have been remobilized locally 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 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. 5). 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. 5). The deposit was 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 basin (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 Creek drainage basin. Locally, polymetallic skarn minerals are present.

A scheelite-molybdenite skarn deposit occurs at the Tungsten Jim mine in the Thompson Creek drainage basin. The deposit, which is 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.

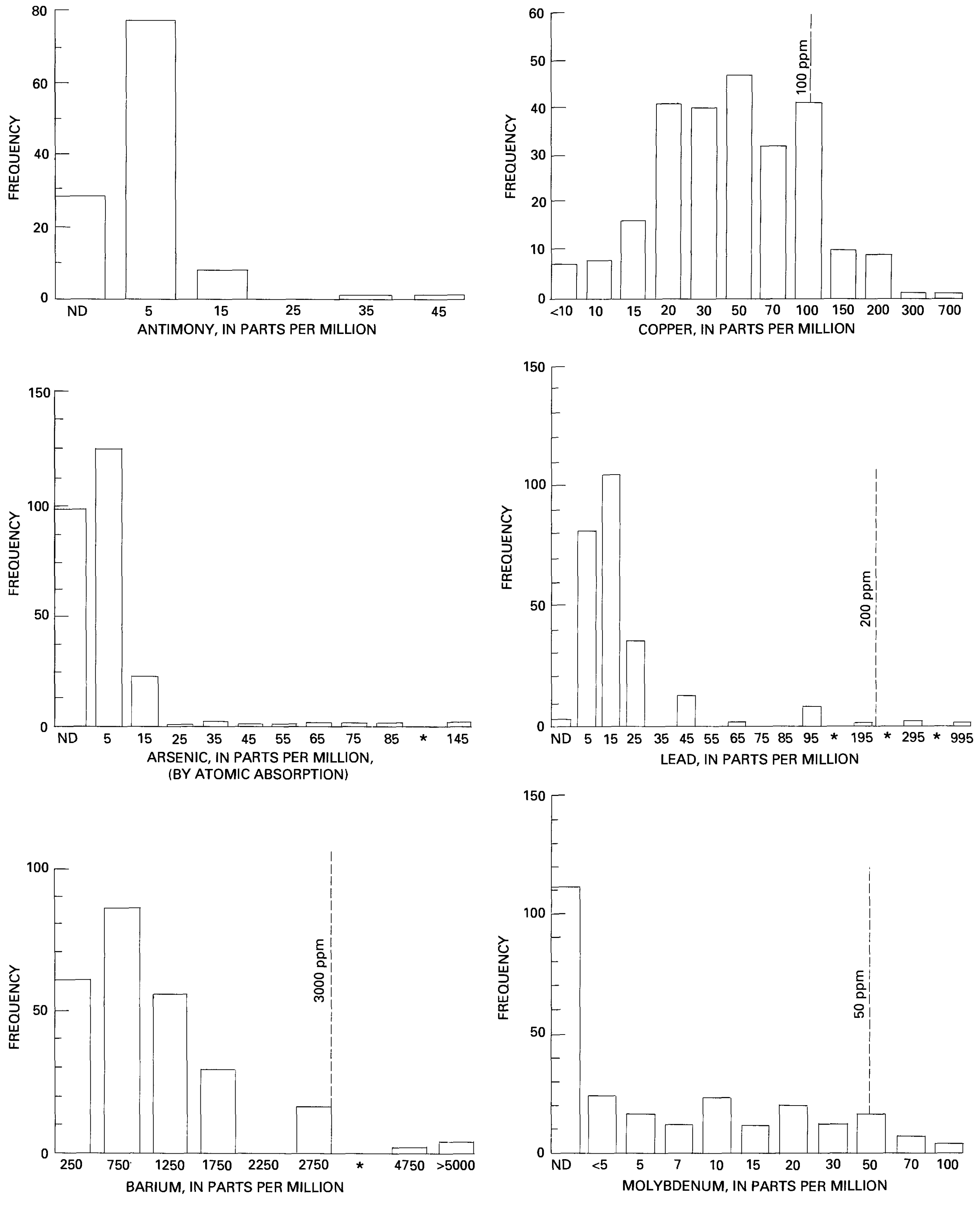
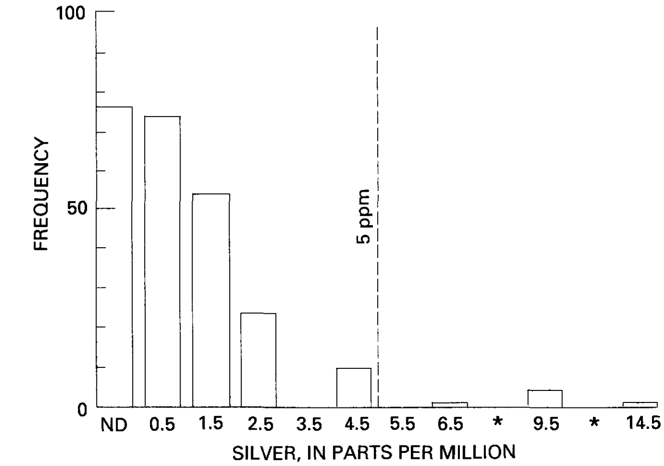
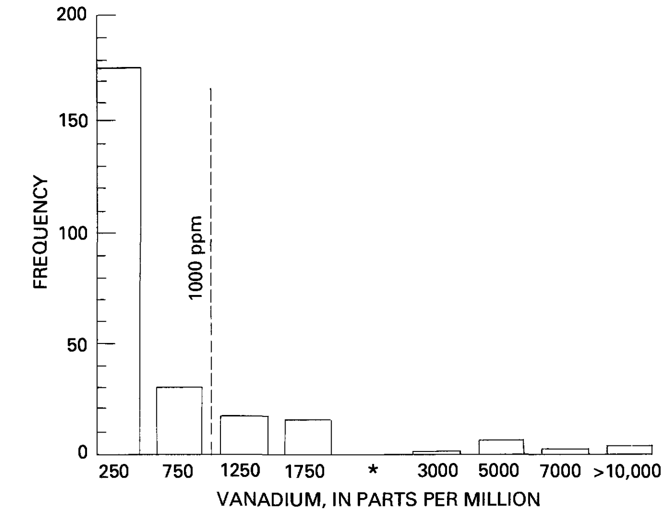
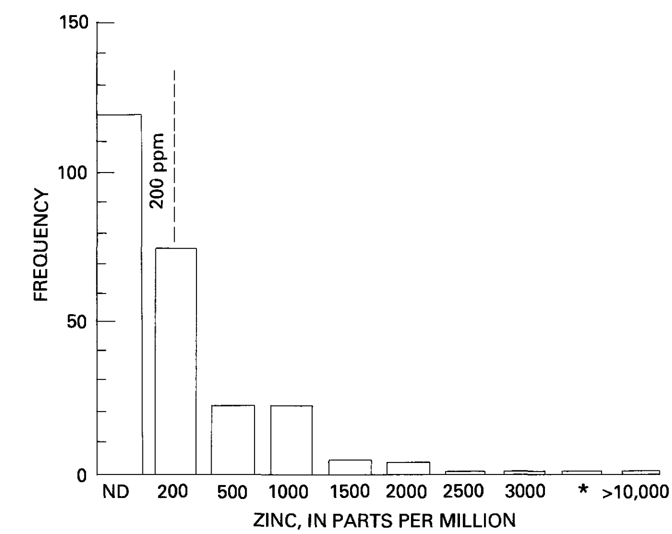


Figure 7 (above and facing page). Frequency distribution of elements in anomalous concentrations as determined in 257 samples of Salmon River assemblage. Data from Fisher and May (1983). Dashed lines show threshold values, based on average black shales reported by Vine and Tourtelot (1970). All samples were analyzed by U.S. Geological Survey laboratories by semiquantitative spectrographic methods except for arsenic, which was analyzed by atomic absorption. ND, not detected; *, scale change; >, greater than; <, less than.


100
50
0
FREQUENCY
5 ppm
ND 0.5 1.5 2.5 3.5 4.5 5.5 6.5 * 9.5 * 14.5
SILVER, IN PARTS PER MILLION


200
150
100
50
0
FREQUENCY
1000 ppm
250 750 1250 1750 * 3000 5000 7000 >10,000
VANADIUM, IN PARTS PER MILLION


150
100
50
0
FREQUENCY
200 ppm
ND 200 500 1000 1500 2000 2500 3000 * >10,000
ZINC, IN PARTS PER MILLION

IDAHO BATHOLITH TERRANE

By Thor H. Kiilsgaard and Earl H. Bennett[3]

The western part of the Challis quadrangle is underlain chiefly by granitic rocks of the Idaho batholith of Cretaceous age (figs. 2 and 8). Intruding the batholithic rocks are a multitude of Tertiary dikes of diverse composition and some Eocene plutonic bodies, a few of which are hundreds of square miles in area. Small roof pendants of metamorphosed sedimentary rocks of uncertain Precambrian-Paleozoic age are distributed erratically across the batholith, mostly near the eastern side. Our geologic mapping and modal analyses indicate the batholithic rocks may be classified into six different major 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, 1992, in pocket). 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, 1992, in pocket) as Idaho batholith (Ki), but probably are chiefly biotite granodiorite. The massive core of the Idaho batholith contrasts with other major batholiths in the western Cordillera that are composed of individually zoned plutons (Mathews, 1958; Bateman and others, 1963).

LITHOLOGY AND MAJOR-ELEMENT COMPOSITION 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 strong 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, normalized to 100 percent and using the method of Streckeisen (1973), show a mean composition of 30 percent quartz, 6 percent potassium feldspar, and 64 percent plagioclase. Major-element composition is shown in table 3.

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

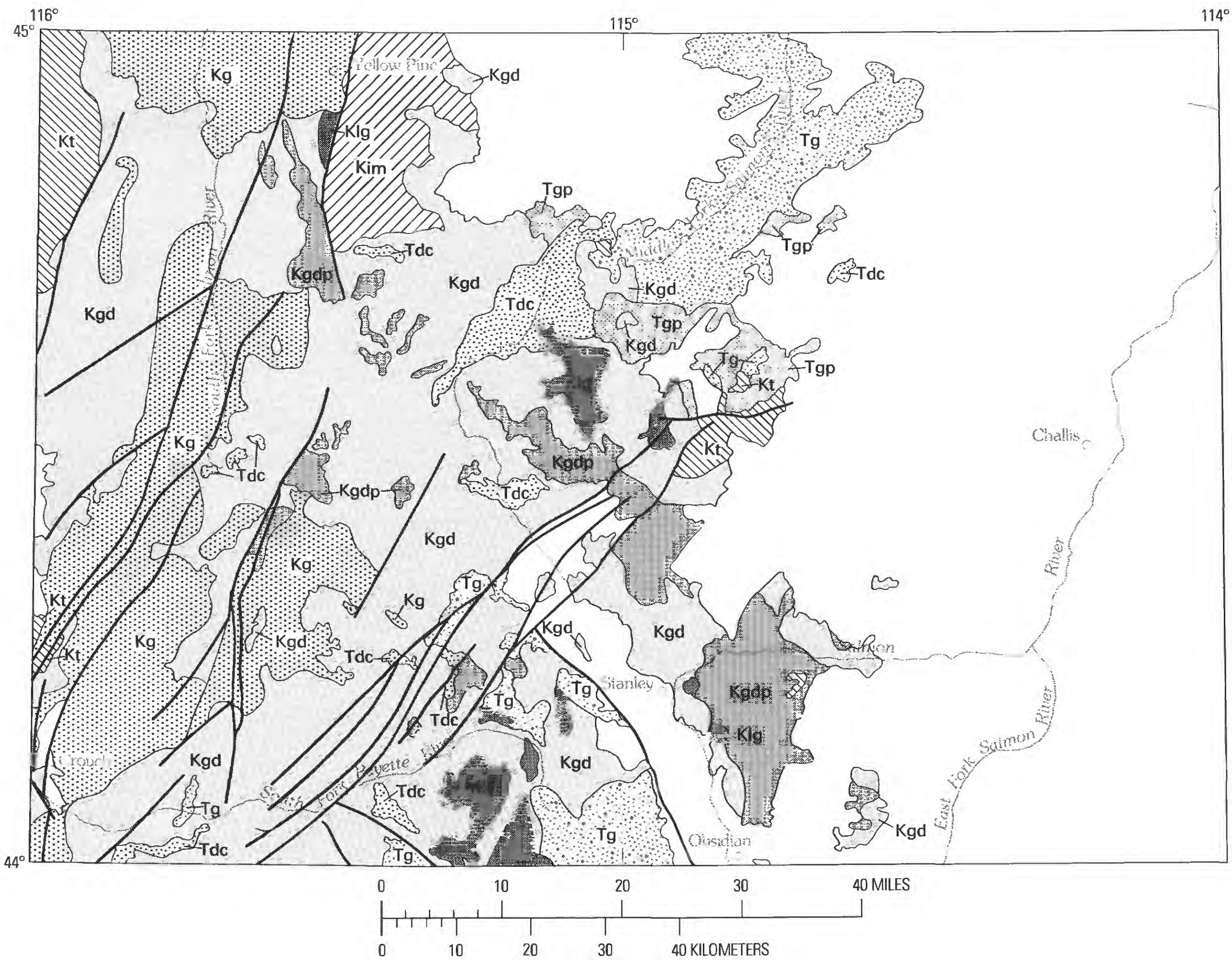
HORNBLENDE-BIOTITE GRANODIORITE

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, which defines a weak to strong foliation. Small crystals of hornblende and sphene are abundant. Modal plots show an average composition of 27 percent quartz, 20 percent potassium feldspar, and 53 percent plagioclase; major-element composition is shown in table 3. 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 potassium feldspar phenocrysts (megacrysts), some as long as 10 cm, were mapped as porphyritic granodiorite. Striking exposures of the coarsely porphyritic granodiorite form a northwest-trending belt that extends more than 75 mi across the central and northwestern parts of the quadrangle (fig. 8). 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 foliated. The megacrysts are poikilitic microcline, generally pink, but white in places. They

[3]Idaho Geological Survey.



EXPLANATION

TERTIARY ROCKS

- **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 ROCKS

- **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 8. Principal exposures of Cretaceous and Tertiary plutonic rocks in the Challis 1°×2° quadrangle, Idaho.

are euhedral in hand specimen but under the microscope show irregular grain boundaries and well-developed Carlsbad twinning. Inclusions are 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 been partly to

Table 3. Mean major-element compositions of Cretaceous and Eocene plutonic rocks in the Challis 1°×2° quadrangle, Idaho.

[Oxides in weight percent. 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
					Cretaceous rocks						
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 rocks						
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.

completely altered 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 resembles tonalite and hornblende-biotite granodiorite; it differs mainly in containing microcline megacrysts, the distribution of which is so variable that modal estimates of composition are not consistent.

BIOTITE GRANODIORITE

Biotite granodiorite is the most common rock type of the batholith and is widely exposed (fig. 8). 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, from alteration of 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. Major-element composition is shown in table 3. Foliation is rare. The rock weathers readily, and most of the surface area is covered by a thick blanket of gruss.

Field relations indicate that most of the biotite granodiorite is younger than the tonalite or hornblende-biotite granodiorite. In the western part of the quadrangle, biotite granodiorite intruded 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. Its relation to the main mass of biotite granodiorite is not known.

MUSCOVITE-BIOTITE GRANITE

Muscovite in granitic rocks of the Idaho batholith is principally 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 mapped this rock as muscovite-biotite (two-mica) granite (fig. 8), using laminated plates or books of muscovite large enough to see in hand specimens as the principal field criterion.

The 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 averaged about 2 percent in the specimens that were studied. The biotite content averages less than 5 percent. Major-element composition is shown in table 3. Other characteristics of the rock are local occurrences of garnet, the absence of hornblende, and the rare occurrence of sphene. The rock is not foliated.

The 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. This 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

The leucocratic granite is light gray to nearly white, is 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 is found only rarely. Hornblende is not found in the rock. Major-element composition is shown on table 3.

The 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. The 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. The 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.

The leucocratic granite contrasts sharply with the other plutonic rocks in its mode of emplacement, being forcibly injected and in places containing 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 and are particularly well exposed 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.

AGE RELATION OF BATHOLITHIC ROCKS

The six types of batholithic rocks in the Challis quadrangle may be grouped according to three periods of emplacement:

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 dating of the rocks supports field evidence that the tonalite-porphyritic hornblende granodiorite on the western and eastern sides of the batholith is the oldest type of plutonic rock and that the leucocratic granite is the youngest batholithic unit. Radiometric ages of the rocks are shown in figure 9. The range in age of rock types indicates overlapping of emplacement, which may or may not be real. Regional Tertiary hydrothermal alteration resulted in argon loss from biotite (Criss and Taylor, 1983), the potassium-argon dating of which, in many localities, reflects 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 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.

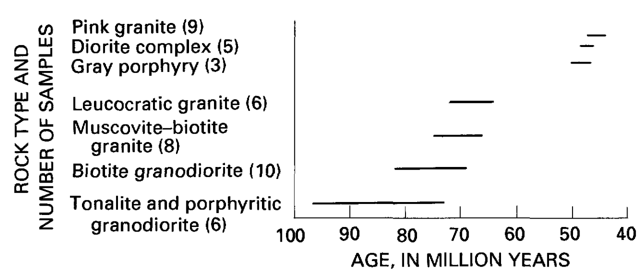


Figure 9. Potassium-argon ages of Cretaceous and Tertiary plutonic rocks in or bordering the Challis 1°×2° quadrangle, Idaho. Dated by R.J. Fleck and R.F. Marvin, U.S. Geological Survey, and R.L. Armstrong (1976).

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.

RELATIONSHIP OF MINERAL DEPOSITS TO BATHOLITH TERRANE

The Idaho batholith is host rock for a number of different types of mineral deposits, but only a few show evidence for a genetic relation to the batholith. Among these are 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 genetic 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 that are 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, having 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. 127). A deposit of molybdenite in stockwork at the head of Cabin Creek in the Mt. Jordan 7½-minute quadrangle 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 nonstrategic quality.

Spatial associations, crosscutting relations, and ages suggest that several base- and precious-metal veins in the batholith may be related to it (Kiilsgaard and Bennett, this volume, p. 103). These include the Deadwood, Mary Blue, and Mary Jane deposits in the vicinity of the Deadwood River and the Eureka Silver King deposit on the South Fork 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, 1992, in pocket).

CHALLIS VOLCANIC TERRANE

By Frederick S. Fisher and Kathleen M. Johnson

The Challis volcanic terrane covers large areas of the northern and eastern parts of the quadrangle (pl. 2; fig. 2). It overlaps the trans-Challis fault system terrane (Kiilsgaard and Fisher, this volume, p. 50; pl. 2) and surrounds parts of the Eocene plutonic terrane (Kiilsgaard and Bennett, this volume, p. 44; 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. The volcanic rocks include lava, flow breccia, and an assortment of pyroclastic rocks including tuff and tuff-breccia. The volcaniclastic sediments include a wide variety of water-laid tuff, mudflows, caldera-wall slump breccia, intra-caldera lake bed sandstone and siltstone, and debris-avalanche deposits. There are small areas of nonvolcanic sediments 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 section on the Eocene 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, 1992, in pocket). 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 lava 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. ago. Cauldrons began to form at about this time with development of the Corral Creek cauldron segment (fig. 2), in the northeastern part of the quadrangle.

Voluminous ash-flow eruptions and major cauldron collapse began about 48.4 m.y. ago with the eruption of the rhyodacitic tuff of Ellis Creek (this unit, as well as all others informally designated in this chapter, is fully described in Fisher and others, 1992, in pocket). Initial subsidence of most of the Van Horn Peak cauldron complex (fig. 2) was associated with this mammoth eruption. Subsequent events that affected parts of the cauldron complex were (1) eruption of quartz latitic tuff (tuff of Eightmile Creek) about 47.5 m.y. ago, triggering subsidence of the Custer graben; (2) accumulation of a thick sequence of rhyodacitic to quartz latitic tuff (tuff of Camas Creek–Black Mountain) within the cauldron complex; and (3) 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. 2) was formed by eruptions of this type between about 46.5 m.y. and 45 m.y. ago. The alkali rhyolitic tuff units in the Castle Rock cauldron segment (fig. 2) are about this age or somewhat older.

A similar sequence of events took place in the Thunder Mountain cauldron complex (fig. 2), beginning around 48–47 m.y. ago. Rhyodacitic ash-flow tuff (dime- and quarter-size lapilli tuff) is the oldest voluminous pyroclastic rock exposed. Subsequent eruptions about 46 m.y. ago produced alkali rhyolitic ash-flow tuff (the informally named Sunnyside tuff). Fine-grained lacustrine sediments and intercalated landslide debris and talus (the informally named beds at Dewey mine) 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 diorite complex plutons are as old as about 47 m.y. (fig. 9). The pink granite ranges in age from about 47 m.y. to about 44 m.y. old; many samples are dated at about 45 m.y. The granitic Casto pluton (Kiilsgaard and Bennett, this volume, p. 44) was emplaced within the Van Horn Peak cauldron complex adjacent to the Thunder Mountain cauldron complex. The Sunnyside tuff and the tuff of Challis Creek are extrusive counterparts of the alkali granite of the Casto pluton.

Extrusive rocks within the volcanic terrane mostly lie flat or dip gently. Near caldera boundaries some beds dip steeply 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, 1992, in pocket).

Many features associated with Challis volcanism and intrusive activity are localized along the trans-Challis fault system (Kiilsgaard and Fisher, this volume, p. 50). Northeast-striking faults of the system outline the Custer graben, the Knapp Creek graben, and the Panther Creek graben and appear to control the shape of the Twin Peaks caldera (fig. 2). The Van Horn Peak cauldron complex straddles the trans-Challis fault system.

HYDROTHERMAL ALTERATION

Hydrothermally altered rocks are common in the Challis volcanic terrane. 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. Elsewhere in the volcanic terrane extensive areas of hydrothermally altered rocks are present in all mining districts. 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).

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 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 production of precious and base metals between 1880 and 1920. Some of the largest early producers were the General Custer, Bismark (Golden Sunbeam), 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 more than 1,000 oz of silver has waxed and waned since the late 1800's; prospecting and mine development continue to the present. Gold and silver have been the major metals of interest, and there has been 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 Pennal Gulch has been quarried for building stone.

RELATIONSHIP OF MINERAL DEPOSITS TO THE CHALLIS VOLCANIC TERRANE

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 (Anderson, 1949). Base metals are not abundant in the veins, and only a few mines have recorded byproducts 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 Gravel Range district. The fluorite occurs as encrusted 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 length along strike (Cox, 1954; Fisher, Johnson, and Hobbs, this volume, p. 116).

Stockwork deposits of precious metals occur in the Gravel Range, Parker Mountain, and Yankee Fork districts. These deposits are associated with dikes and small rhyolite domes emplaced near the surface. The locations of the dikes and domes were controlled, in large part, by structures associated with the trans-Challis fault system (Kiilsgaard and Fisher, this volume, p. 50). 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 (Johnson and Fisher, this volume, p. 135).

Stratabound precious-metal deposits in the Thunder Mountain cauldron complex 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 (Fisher and Johnson, this volume, p. 154), and deposits in intracaldera tuff, as at the Sunnyside mine (Fisher and Johnson, this volume, p. 157). At the Dewey mine, gold and silver occur as free gold and electrum in cracks and seams in dark, carbonaceous mudflows, conglomerate, and sandstone. At the Sunnyside mine, gold and silver in a gangue of quartz, clay, sericite, and pyrite are present along fractures in a blanketlike altered zone in the Sunnyside tuff.

Uranium occurs in arkosic sediments at the base of the Tertiary section in the Custer graben, 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). The 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). Circulation of 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. Movement of fluid 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 Proterozoic, Paleozoic, and Cretaceous rocks and redeposited the metals as vein, stockwork, stratabound, and replacement deposits 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 TERRANE

By Thor H. Kiilsgaard and Earl H. Bennett[4]

Eocene plutonic rocks in the Challis quadrangle are part of a diorite-granite bimodal group. The two types are mineralogically and chemically distinct. Associated with each plutonic type are hypabyssal intrusive rocks that collectively form swarms of dikes that are common in the area of the pluton. Also, the distribution and similarity of compositions suggest that each group of hypabyssal dikes is equivalent to volcanic rock units that are part of the Challis volcanic field. 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. 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 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. 8). These rocks range from nonporphyritic diorite to porphyritic granodiorite, with quartz monzodiorite grading to porphyritic granodiorite most prevalent. The porphyritic units commonly 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 complex is chemically distinct from the granitic rocks (table 3).

Dioritic rocks of Tertiary age were first recognized in the northeastern 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, 1992, in pocket). 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, 1992, in pocket) 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, 1992, in pocket). 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 probably related to it. The two rock types have similar mineral composition, color, and radiometric ages (fig. 9).

PINK GRANITE

The Eocene granite is distinguished by its coarse granitoid texture and abundant perthitic potassium feldspar, which makes the rock a characteristic pink. 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. The Tertiary granite has an average uranium, thorium, and potassium content that is two to three times greater 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 Eocene granite. Steep jointing tends to produce sharp spires and steep topography. This is in contrast to the Cretaceous batholith, which has a more subdued topographic expression and concordant elevations.

An average modal composition of the granite is 31 percent quartz, 37 percent potassium feldspar, and 31 percent plagioclase. Biotite is present in quantities ranging from 2 to 5 percent, and hornblende is sparse. Sphene, allanite, monazite, zircon, apatite, and magnetite are the accessory minerals.

The Eocene pink granite tends to be similar chemically to the felsic Cretaceous plutonic rocks; however, the Eocene granite generally has less aluminum, magnesium, and calcium and more potassium (table 3). Eocene granite contains more rubidium and less strontium than the Cretaceous plutonic rocks (fig. 10), and more of the incompatible trace elements, including tin, tungsten, thorium, uranium, molybdenum, niobium, zirconium, fluorine, and beryllium.

[4]Idaho Geological Survey.

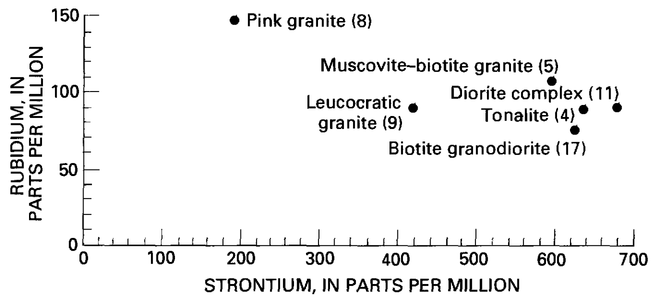


Figure 10. Rubidium and strontium concentrations in plutonic rocks, Challis 1°×2° quadrangle, Idaho. Number of analyses given in parentheses. Analyses by R.J. Fleck and B. Hatfield, U.S. Geological Survey.

Biotite in the granite tends to be rich in iron (Bennett and Knowles, 1985).

TERTIARY DIKES

Numerous 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 follow faults and also 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 commonly contain phenocrysts of biotite and hornblende. The dike rocks, particularly the rhyolite-quartz latite dikes, are noticeably altered. Feldspar minerals are altered to sericite, biotite to chlorite. In some places, pyrite in the dike rocks is oxidized to goethite, which commonly gives rhyolite outcrops a reddish tint. Quartz phenocrysts are rounded and embayed.

Rhyolite dikes show a close spatial and compositional affinity to the Eocene pink granite. Rhyolite dikes, like the pink granite, are more radioactive than other dikes, and are clustered near exposures of the pink granite. Good exposures are 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 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 in the dike swarm east of Garden Valley along the South Fork Payette River and along Rapid River (Fisher and others, 1992, in pocket).

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 low. These dates, plus field evidence, suggest that most of the dikes are of Eocene age.

REGIONAL 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) called attention to widespread regional alteration around Tertiary plutonic bodies and described 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.

RELATIONSHIP 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 and silver content but that also contain needed 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 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 district also are in Eocene intrusive rhyolite, as are gold-silver veins at Parker Mountain (Kiilsgaard and others, 1989). In the Yellowjacket district, Anderson (1953) described the source of deposits of gold, silver, and base metals as early Tertiary magma and noted that ore-bearing fractures cut all dikes except lamprophyres. 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 stockworks (pl. 1), 3.5 mi north of Yellow Pine, contains gold, molybdenite, scheelite, and stibnite, which Erdman and others (1985) concluded 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 (oral commun., 1985) concluded that mineralization at the Yellow Pine and Meadow Creek mines is of Tertiary age.

Gold in a rhyolite dike at the Iron Crown mine (pl. 1), northeast of Stanley, was 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-striking Tertiary dikes and appear to be genetically related to them. Gold-silver resources at the two mines were summarized by Kiilsgaard and Van Noy (1984).

In a general sense, the mineralogy, textures, alteration effects, and regional trends of veins containing gold, silver, and base metals 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 formed in similar pressure-temperature environments of a mid-Tertiary mineralizing epoch and with a common relation to 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, 1954a,b). Fluorite-gold-silver veins near the mouths of Big and Little Casino Creeks (44°15′ N., 114°51′ W.) east of Stanley 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 Salmon River. Some fluorspar deposits at Keystone Mountain (44°26′ N., 114°21′ W.), near Challis, are in Cambrian and (or) Ordovician Bayhorse Dolomite. Anderson (1954a) 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 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. Kern (1959) believed the uranium ores in all of the deposits formed contemporaneously from a common source, but Choate (1962) 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 weathering of the primary pitchblende-bearing veins. The age of pitchblende in the veins is not known with certainty, but the presence of radioactive stringers in a basalt dike at the P & B property (Choate, 1962) and the occurrence of pitchblende in northwest-striking 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 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 Holocene 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 (Mackin and Schmidt, 1956; Williams, 1961); 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 in the quadrangle, in places hundreds of feet above valley floors and well away from glaciated areas. 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 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) reported 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 the Sunbeam mine along the Salmon River, together produced more than 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 more than 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 5–10 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 flat-topped summits 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 bedrock on the surface is deeply decomposed. Soil on the surface of the summits and soil and eluvium on valley walls were 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 terrane. The Quartz Creek mine, located about 2 mi northeast of Yellow Pine, produced about 800 lb 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 more than 118,800 lb WO_3 in 1954–55 (Cater and others, 1973, p. 210). A considerable proportion of the ore was concentrated from scheelite-rich talus.

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-striking, 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-striking high-angle faults, aligned grabens, a caldera, and roughly aligned Eocene intrusions that extends across the quadrangle from southwest to northeast (pl. 2; fig. 11). 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 projected 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, Proterozoic, and Challis volcanic terranes, but is identified as a separate and distinct terrane because of the profound controlling influence of the fault system on igneous intrusion, volcanotectonic structural development, and ore deposition along its entire length.

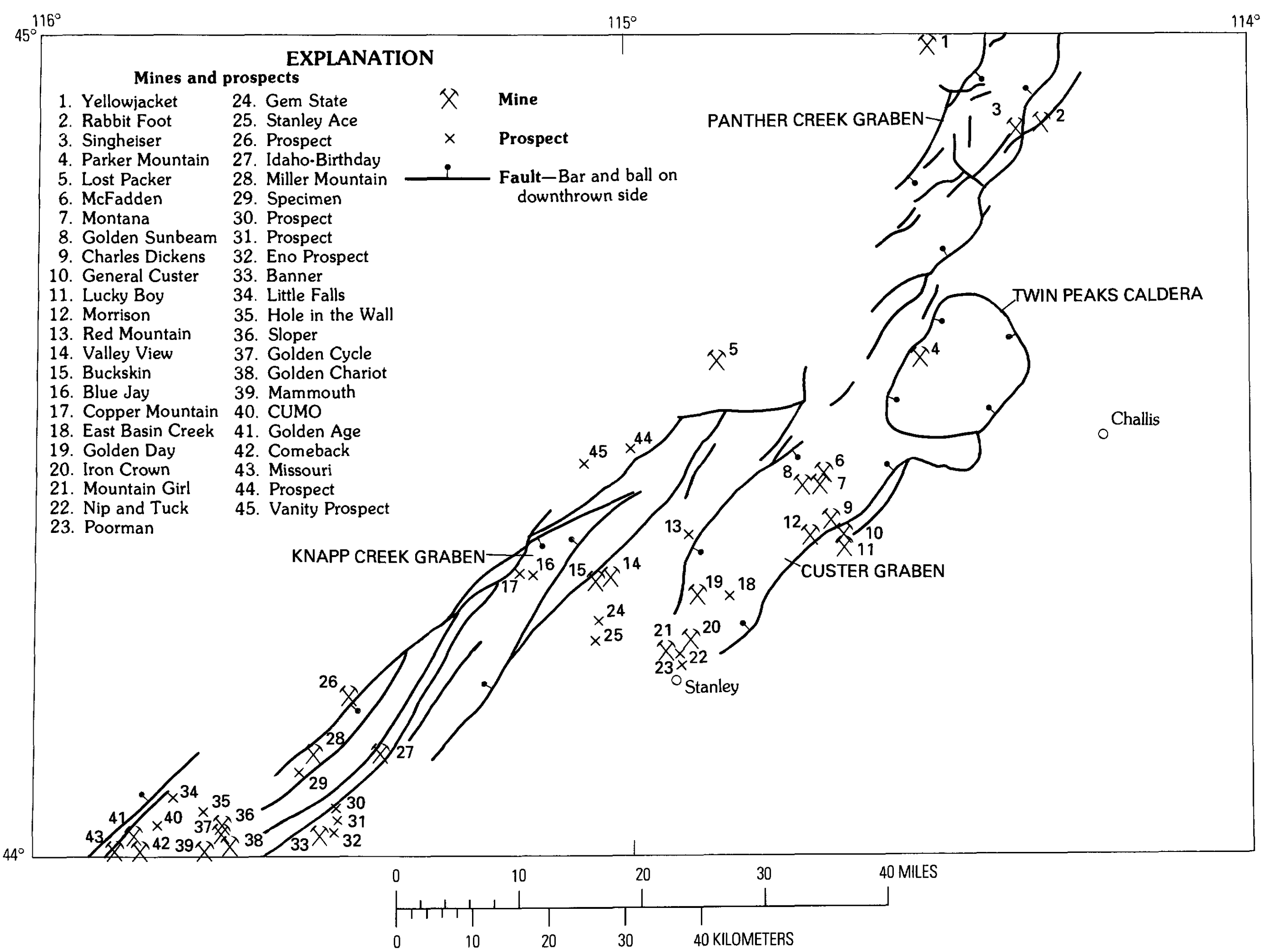


Figure 11. The trans-Challis fault system and related mineral deposits, Challis 1°×2° quadrangle, Idaho.

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 most intensely sheared zone are so altered that their original character 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 faulting.

The high-angle faults west-northwest of Stanley are aligned with the Panther Creek graben (Ekren, 1985; Fisher and others, 1992, in pocket) 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. 11; pl. 2) does there appear to be a break in the fault system, but this break is compensated for 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, and irregular plugs and domes are present in the Custer graben, the Van Horn Peak cauldron complex, and the Panther Creek graben (Fisher and others, 1992, in pocket). Many of these intrusive bodies are linear and coincident with the trans-Challis fault system. The rhyolite bodies were emplaced at high levels in the crust, and several reached the surface. Most of the plugs and domes are small (less than 1 sq mi); however, one rhyolite stock and flow complex is exposed over about 75 sq mi (Hardyman and Fisher, 1985). The rhyolite bodies 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 these bodies 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 Proterozoic 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 Proterozoic movement along the fault (O'Neill and Lopez, written commun., 1984). Faults of the system clearly displace granitic rocks of the Idaho batholith of Late Cretaceous age and 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.

RELATIONSHIP OF MINERAL DEPOSITS TO FAULTS

Many epithermal mineral deposits in the Challis quadrangle show a spatial relation to the trans-Challis fault system (fig. 11) and appear to be genetically related to structures of the system and to Eocene rocks that were intruded along it (Kiilsgaard and Bennett, 1985). Most of the deposits have been mined for silver and gold, but some have yielded lead, zinc, and copper as byproducts. Several molybdenum-copper deposits along the fault system have been explored, but none has been brought into production. Fluorspar has been mined from deposits in the Panther Creek graben, and uranium was produced 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°00′N., 115°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, and other dikes cut veins. This combination of relationships indicates that the veins and dikes were emplaced at about the same time. Potassium-argon ages of biotite and hornblende from Eocene plutonic rocks along the fault system range from about 45 to 50 m.y. 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 for zircon from a rhyolite dike at the Little Falls deposit (pl. 1) was 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 wallrock 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 intrusive rocks 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. 11), where gold values are in the range of 0.02–0.03 oz per ton. The Lost Packer and Parker Mountain deposits (pl. 1; fig. 11) also have been explored, as have the CUMO, Little Falls, and Idaho Birthday deposits (pl. 1; fig. 11), in the southwestern part of the quadrangle. The Singheiser and Rabbit Foot deposits (pl. 1; fig. 11), in the northeastern part of the quadrangle, have produced only a few hundred ounces of gold each, but may be targets for large-tonnage, low-grade gold mining operations.

GEOPHYSICAL ANOMALIES

By Michael W. Webring and Don R. Mabey

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 that have a wide range of densities and magnetic properties (Mabey and Webring, 1985). The Proterozoic 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 muscovite-biotite 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 values; however, enough information is available to support qualitative generalizations. The sedimentary and most of the metasedimentary rocks are weakly magnetic; however, magnetite-rich zones in the Proterozoic metasedimentary rocks are strongly magnetic. Most of the rocks of the Idaho batholith are weakly to moderately magnetic whereas the Eocene plutons are generally more strongly magnetic. The magnetic character of the Eocene volcanic rocks covers a wide range. Some volcanic units are strongly magnetic, remanent magnetization, both normal and reversed, being 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, the high elevations buoyed up by deficiencies in mass 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 having a thickness equal to the average elevation within 38.5 mi of the station (fig. 12). This method of calculating the regional gravity surface is described by Mabey (1966). 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. 13) 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 Proterozoic 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 overlain by Eocene volcanic rocks and Cenozoic sediments.

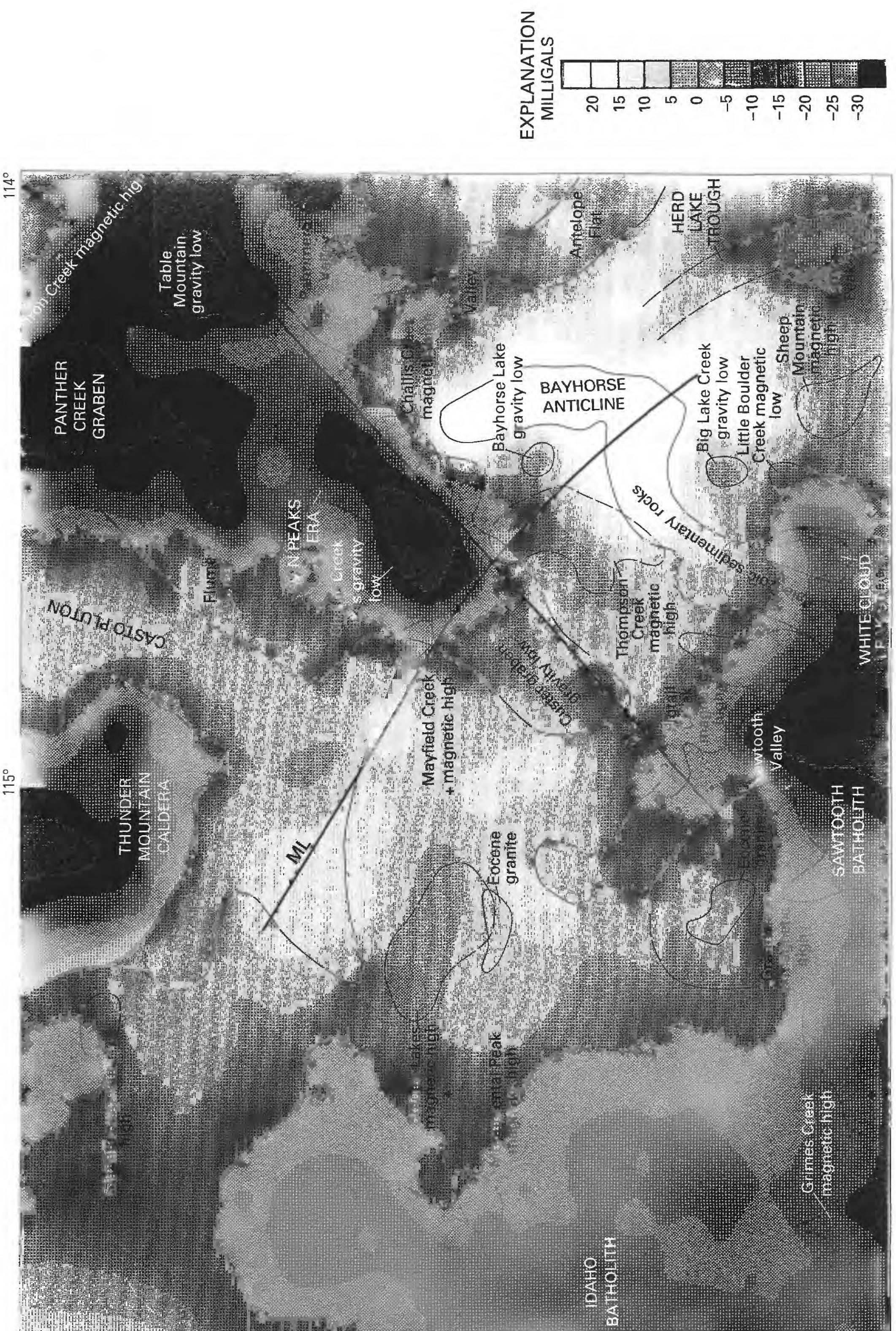


Figure 12. Residual gravity anomaly map of the Challis 1°×2° quadrangle. ML, Mayfield lineament; YFL, Yankee Fork lineament.

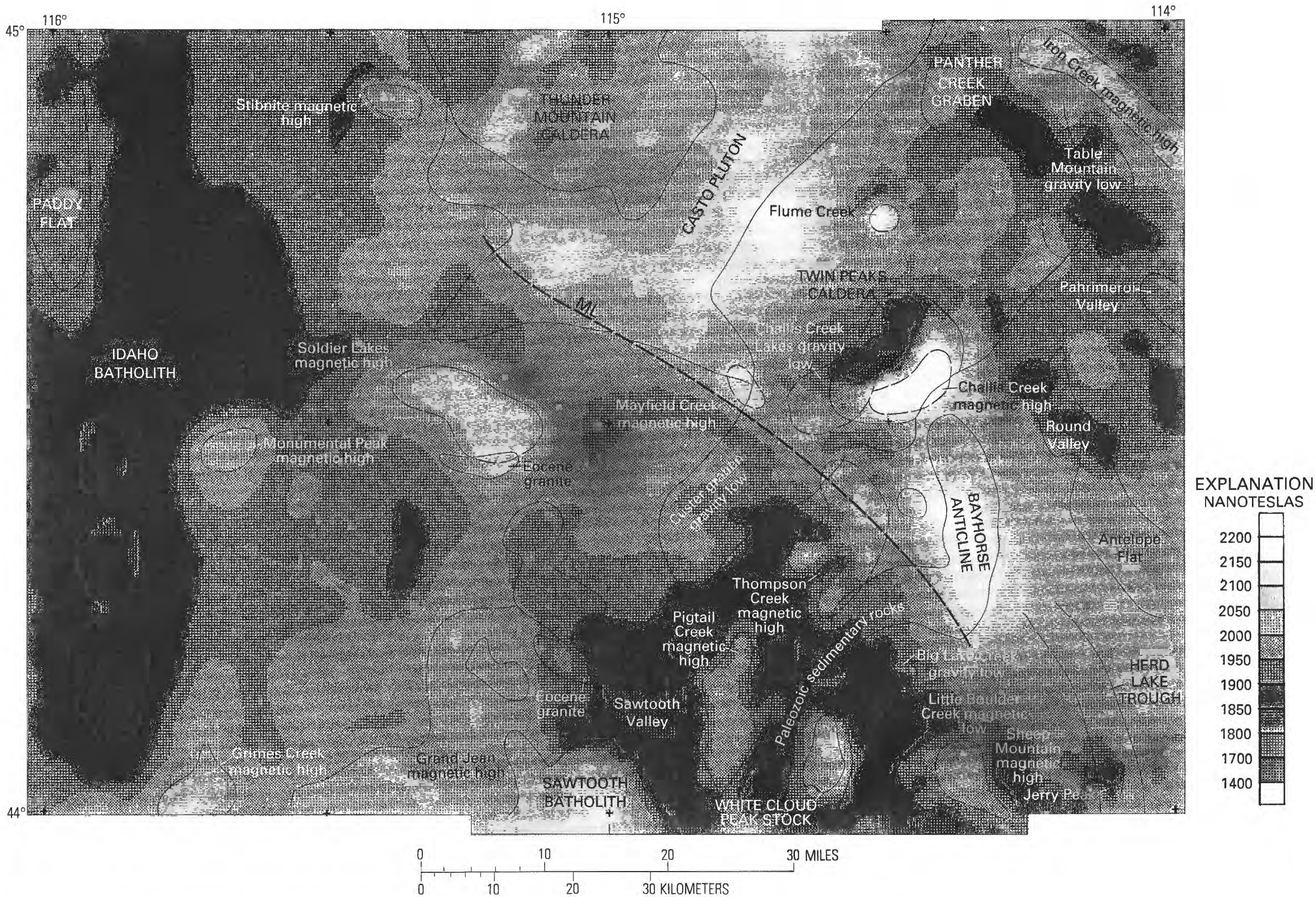


Figure 13. Residual aeromagnetic anomaly map of the Challis 1°×2° quadrangle. Flown at 12,000 ft. ML, Mayfield lineament.

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 that contains no apparent Tertiary intrusive bodies 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 deficiency in mass at depth is greater than required to compensate for the average elevations.

MONUMENTAL PEAK HIGH

A magnetic high in the area of Monumental Peak (fig. 13) reflects a partly exposed intrusive body of Eocene diorite. The body, which is elongate east-northeast, appears to be dome shaped and substantially more extensive than the surface exposures. This body is 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.

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 that is 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 cauldron complex), 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-trending 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 cauldron complex. 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 producing the anomaly, but the magnetic anomalies have a north-northeast trend. There are two magnetic highs 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 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 body within the batholith. This intrusive body may be related to the mineralization in the area.

CASTO PLUTON

An arcuate gravity and magnetic high is present 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 having moderate magnetization. A gravity low is approximately coincident with the magnetic high. There are small masses of Eocene intrusive rock 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 (D.R. Mabey, unpub. data, 1980) 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 metasedimentary rock north and east of the Sawtooth batholith (Fisher and others, 1992, in pocket) is apparent. The magnetic nose on the west side of the metasedimentary rock may reflect a southward extension of the Eocene intrusive body cropping out to the north.

SAWTOOTH BATHOLITH (44°08′ N., 115°01′ W.)

A large magnetic high is coincident with the Sawtooth batholith and the form of the anomaly indicates that at least the northeastern 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 northeastern edge of the batholith, the magnetic anomaly suggests that the north edge of the magnetic body is as much as 3 mi south of the exposed contact. Thus, the part of the Sawtooth batholith 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 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 (pl. 2). The gravity anomaly produced by the batholith appears to have an amplitude of about 15 mGals and be centered under Sawtooth Valley. A mass having a density contrast of -0.1 g/cm^3 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 (Criss and Champion, 1984, fig. 13; Mabey and Webring, 1985) 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 a low-density mass under the Sawtooth Range related to the Sawtooth batholith.

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 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 cauldron complex, but there are four large magnetic highs 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 a closed gravity low coincident with the Panther Creek graben as defined by McIntyre and others (1982). The gravity anomaly could be produced by about 9,850 ft of graben fill having a –0.3 g/cm^3 density contrast. The anomaly indicates that the thickest part of a prism of fill is bounded on the east by a mapped fault and by a parallel fault about 4–8 mi to the west. The west 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°47′ N., 114°32′ W.) and Camas Creek. The anomaly appears to reflect a strongly magnetized body near the surface. No gravity stations were established directly over the magnetic body, but adjacent stations define an elongate low in which the lowest Bouguer anomaly values are for 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 a shallow intrusive body.

CHALLIS CREEK MAGNETIC HIGH

The highest amplitude magnetic anomaly in the Challis quadrangle is a high along Challis Creek (44°34′ N., 114°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°33′ N., 114°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 northeastern 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 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, there is a smaller magnetic high 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 body, 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 body 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 continuing southwest from Challis Creek Lakes low has a 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 that 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) including 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 is 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-trending grain of both the gravity and magnetic anomalies. Tertiary volcanic rock is widespread over the zone, and Quaternary alluvium covers most of the largest valleys. However, Paleozoic and Proterozoic 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 overlying 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 (Mabey and Webring, 1985). 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. 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 gravity low of about 30 mGals in Pahsimeroi Valley (44°40′ N., 114°02′ W.) indicates 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 milligals. 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, 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 fault displacement 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 data; 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 depression consists of several segments, it appears to be a continuous structural feature.

The gravity low in Round Valley and in Antelope Flat 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 (Lemhi, 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. 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 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 that have 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 Proterozoic metasedimentary rocks, mostly siltite, either crop out or are 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 the Yellowjacket Formation is coincident with the crest of the magnetic high. Bouguer gravity values increase northeast across the area of the Iron Creek magnetic high, but no obvious gravity anomaly coincides with the magnetic anomaly.

In the Challis quadrangle the magnetic anomaly has an amplitude of about 200 gammas at a flight level 3,200–6,500 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 northwestern 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 ends abruptly a few miles southeast of the mine.

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

TABLE MOUNTAIN (44°48′ N., 114°13′ W.) LOW

Between the exposed Proterozoic 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°50′ N., 114°12′ W.) on the west and low in the Hat Creek drainage basin (44°47′ N., 114°03′ W.) on the east. The low occurs in an area of Tertiary volcanic rock and is coincident with the Corral Creek cauldron segment (fig. 2). It appears to reflect a local depression containing volcanic rock about 0.5 mi thick. The southern part of the low has a steep gradient. 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 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 steep gravity gradient. The amplitude of the gravity high decreases rapidly southward near the confluence of the East Fork Salmon River and Herd Creek (44°09′ N., 114°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 Lake 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 body 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 body dated as 93 m.y. (S.W. Hobbs, oral commun., 1981). There are small gabbro dikes and sills in the Bayhorse high, 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. 4) 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 would have 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 among 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.-old Juliette stock. McIntyre and others (1976) considered 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 body may underlie the area.

In the Thompson Creek–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.

There are two gravity lows near the west edge of the Bayhorse high. The Bayhorse Lake (44°24′ N., 114°24′ W.) low, which is inferred to be within the Bayhorse high, is underlain by Tertiary volcanic rock. It coincides with a nose on the northwest corner of a regional magnetic high. There is a similar gravity low 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 intrusive rocks.

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 0.5 mi of the surface. Geologic mapping (Fisher and others, 1992, in pocket) 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 molybdenum mine at Thompson Creek (pl. 1). The others occur over Tertiary volcanic rock.

LITTLE BOULDER CREEK MAGNETIC LOW

The most intense magnetic low in the Challis quadrangle is west of the East Fork Salmon River in the Little Boulder Creek area (44°04′ N., 114°32′ W.). The anomaly occurs over volcanic rock and has a source near the surface. It presumably indicates surface or near-surface volcanic rock having 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 coincides with the surface contact between the batholith and the older sedimentary rocks, thereby indicating a high-angle contact. To the north the contact is 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 is a northeast-trending lineament 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 (fig. 12). Throughout most of its length the lineament forms the northwest edge of the gravity high that dominates the southeastern part of the quadrangle. Its southwest end forms the northwest edge of the lowest part of the gravity low over Sawtooth Valley (44°05′ N., 114°51′ W.) and the 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. The Yankee Fork lineament is approximately parallel to the trans-Challis fault system and 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 6–9 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 largest gravity and magnetic anomalies are associated with features involving rocks ranging in age from Proterozoic through Holocene in a complex structural setting. In the central part of the quadrangle the largest anomalies are produced by Eocene extrusive and intrusive igneous rocks. In that area, 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, the larger anomalies reflecting Eocene plutons within the Idaho batholith.

GEOCHEMISTRY

By Kathleen M. Johnson

A 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 geochemical studies were done in the course of other investigations. These studies commonly focused on a specific rock or deposit type; the geochemical study was typically designed to characterize the rock or deposit type or to improve geochemical prospecting techniques. Results of most of these studies have been published and are referenced below; 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 contribute to resource assessment.

REGIONAL STUDIES

The objectives of the regional stream-sediment geochemistry program were to provide information on geochemical trends, to relate those trends to specific lithologic units or structural features, and to locate areas having anomalously high concentrations of one or more elements that might reflect altered zones or mineral deposits. 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 under the direction of J.E. Callahan and G.J. Neuerburg. The following descriptions of sample design and analytical technique are partly derived from unpublished manuscripts by the samplers.

Previous geochemistry studies in the quadrangle included reconnaissance stream-sediment sampling programs in four areas (pl. 1): the Sawtooth Wilderness Area (Kiilsgaard and others, 1970), the Idaho Primitive Area[5] (Cater and others, 1973), the Sawtooth National Recreation Area (Tschanz and Kiilsgaard, 1986), and the Ten Mile West Roadless Area (Kiilsgaard, 1982). These areas were not resampled for this study.

In addition, the National Uranium Resource Evaluation (NURE) program 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, and analytical methods 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). We made no further analysis of these data.

[5]Now included in the Frank Church–River of No Return Wilderness.

SAMPLING TECHNIQUES

In the parts of the quadrangle that were sampled for this project, first- and second-order streams were sampled because their relatively small drainage basins suggest that sediment obtained is likely to be representative of lithologies and mineral occurrences drained. In all, 2,516 individual sample sites were chosen on the basis of local stream density and accessibility. Sample density is about one sample per 3 sq mi (McDanal and others, 1984).

At most sample sites both a stream-sediment sample and a panned-concentrate sample were collected (McDanal and others, 1984). A water sample was also collected at each site where water was available. Stream-sediment samples were composited from several localities within an area that may extend as much as 100 ft from the spot recorded on the map. Panned concentrates were taken from the same active alluvium as the stream-sediment samples. Each bulk sample was sieved through a 2.0-mm (10-mesh) stainless steel screen. The fraction that passed through the screen was then panned until most of the quartz, feldspar, organic material, and clay-sized material was removed.

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 for analysis on the basis of a brief orientation survey carried out in the Thompson Creek (pl. 1) drainage basin in 1979 (Callahan and 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.

The best fraction of the panned concentrates for outlining deposits containing molybdenum and tungsten was found to be the nonmagnetic-heavy-mineral separate (Callahan and others, 1981a, 1981b). The heavy-mineral fraction was separated in bromoform (specific gravity 2.89) and was further subdivided, by means of a Frantz Isodynamic Separator, 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 such as scheelite 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 by means of 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 are reported in weight percent. For convenience, table 4 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.

Table 4. Conversion of parts per million (ppm) 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	Ounces per ton	Ounces 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

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 2,355 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) provided 197 samples. Sampling in the Sawtooth Wilderness Area (Kiilsgaard and others, 1970) yielded 342 samples. Tschanz and Kiilsgaard (1986) 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 because we attempted 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 sampling and analytical 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, including spectrographic analyses of stream-sediment samples for 18 elements and chemical analyses for citrate-extractable heavy metals, cold-extractable copper, and arsenic. The data from the Sawtooth Wilderness Area are similarly limited to the published report, but include only spectrographic analyses of stream-sediment samples for 24 elements. Another important difference between the various data sets is in the detection limits, which have generally improved over the past 20 years. 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 Wilderness 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 the three areas are shown in table 5.

The purpose of statistical analysis of the two final data sets was to define anomalous levels of the analyzed elements. Elements or suites of elements are useful for characterizing geologic trends, such as the geologic terranes previously described, as well as areas of altered or mineralized rock. Some of these elements are useful in outlining areas having potential for undiscovered mineral deposits. Other elements are more useful in the general characterization of geochemical trends. The primary tool for defining anomalous levels or "thresholds" 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. Histograms for elements determined in stream sediments and panned concentrates are shown in figures 14–16.

Anomalous levels are defined as 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 element distribution in unmineralized rocks and to avoid assigning anomalous levels that are actually too high due to extensive oversampling of mineralized rock. Anomalous levels are shown in table 6.

Table 5. Limits of determination for spectrographic analyses of stream-sediment and nonmagnetic heavy-mineral-concentrate samples.

[Limits from McDanal and others, 1984]

Element	Lower limit of determination for minus-200-mesh stream sediments	Lower limit of determination for nonmagnetic heavy-mineral concentrate	Upper limit of determination
	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

DISTRIBUTION OF GEOCHEMICAL ANOMALIES

Sites having anomalous values were plotted on geologic maps for comparison with rock units, structures, and known mineral deposits (Johnson and others, unpub. data, 1989). This report contains 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.

It is well known that geochemical backgrounds vary with source-rock composition (Levinson, 1980). The reader is cautioned to consider the influence of the complex geology and the data-handling techniques on the interpretation of Challis geochemistry. The geologic map of the Challis quadrangle shows more than 100 rock units (Fisher and others, 1992, in pocket); these units can be combined into seven lithologic 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 the source area for each sample. 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 granodiorite is 20 ppm, in shale

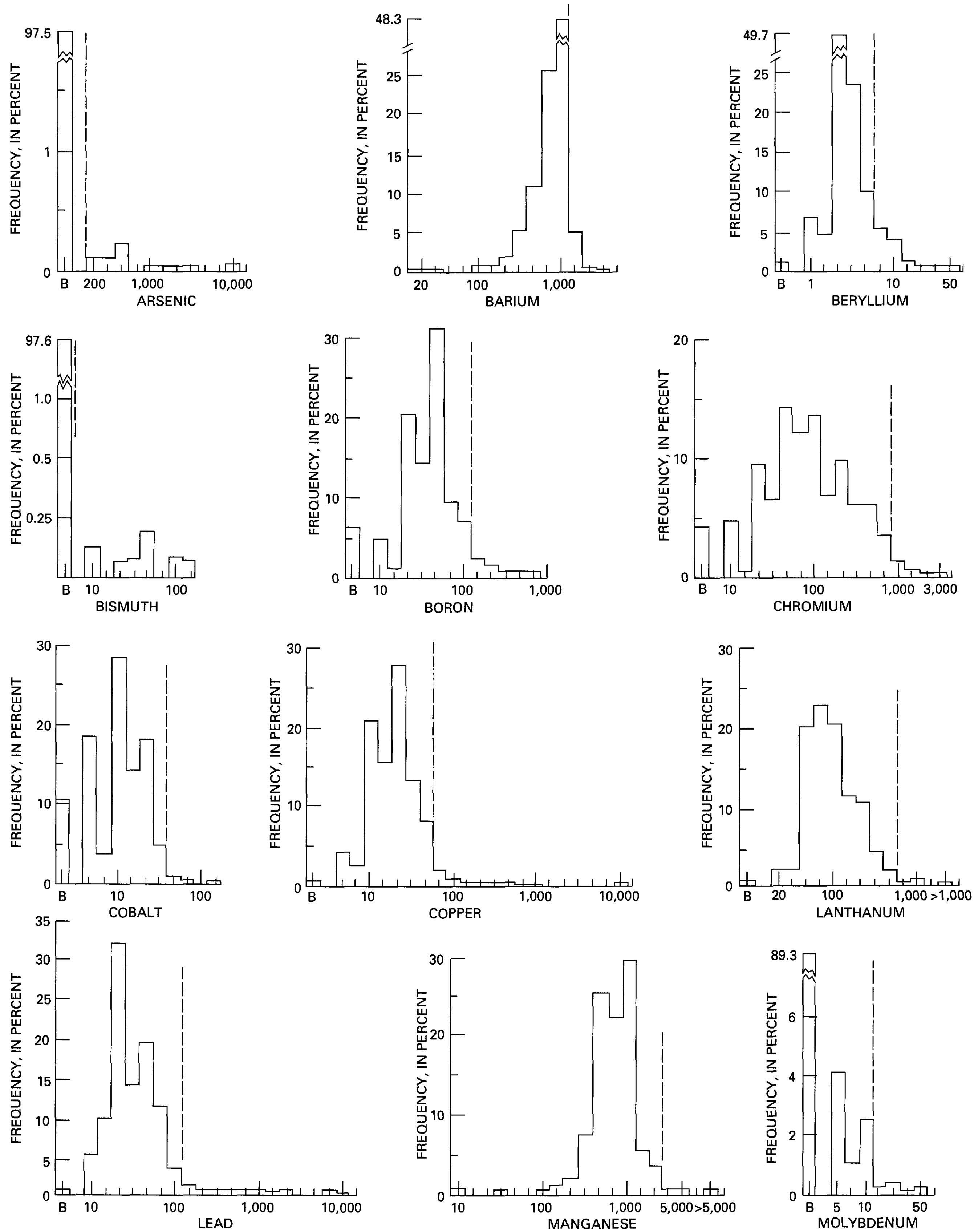
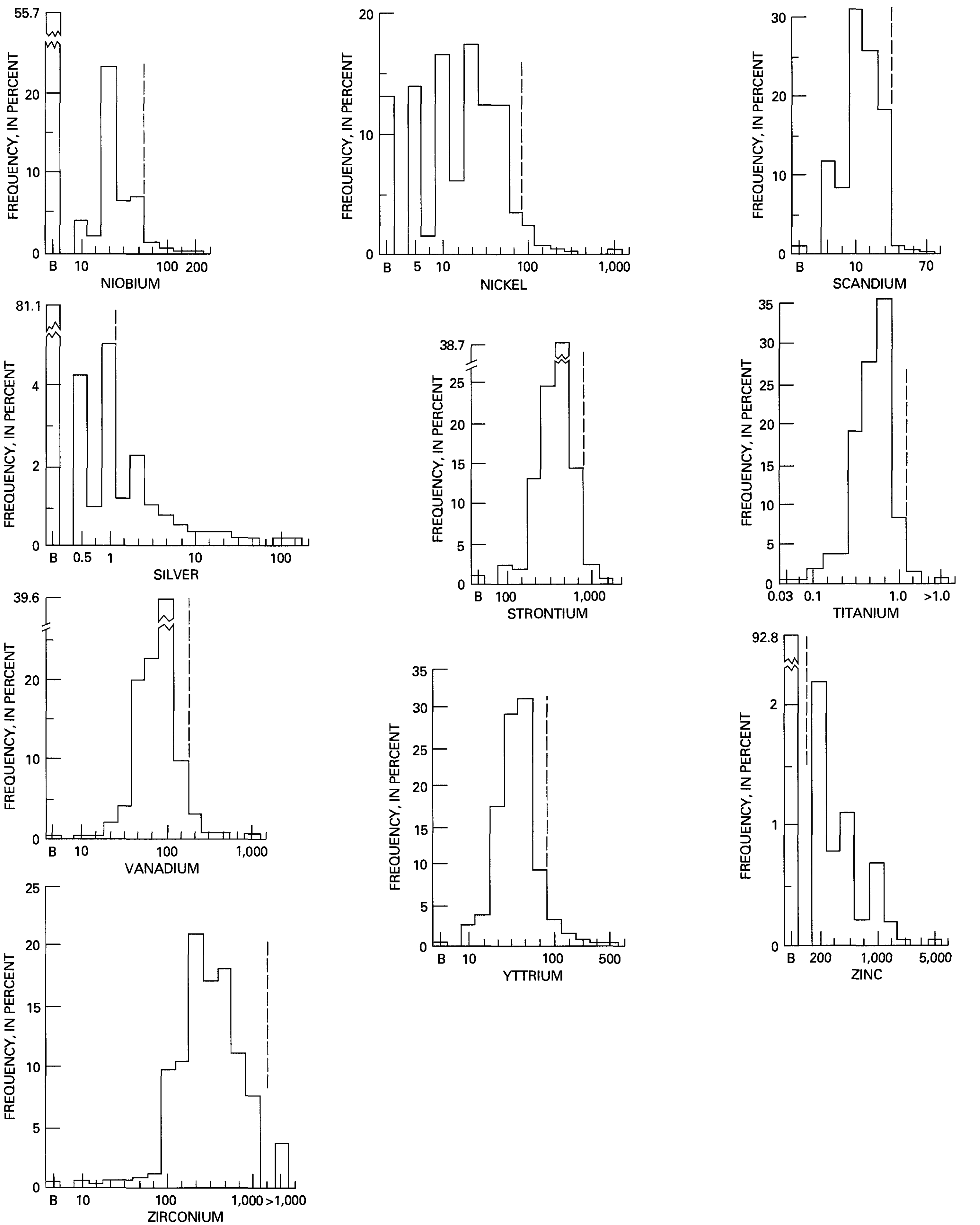


Figure 14 (above and facing page). Histograms for spectrographic analyses of stream-sediment samples from Challis CUSMAP, Ten Mile West Roadless Area, and Sawtooth National Recreation Area. All values reported in parts per million except titanium, which is in percent. Values to right of dashed line are considered anomalous. B, below limit of detection; >, greater than. N = 3,211.


55.7
FREQUENCY, IN PERCENT
0 10 20
B 10 100 200
NIOBIUM
20
FREQUENCY, IN PERCENT
0 10
B 5 10 100 1,000
NICKEL
30
FREQUENCY, IN PERCENT
0 10 20
B 10 70
SCANDIUM
81.1
FREQUENCY, IN PERCENT
0 2 4
B 0.5 1 10 100
SILVER
38.7
FREQUENCY, IN PERCENT
0 5 10 15 20 25
B 100 1,000
STRONTIUM
35
FREQUENCY, IN PERCENT
0 5 10 15 20 25 30
0.03 0.1 1.0 >1.0
TITANIUM
39.6
FREQUENCY, IN PERCENT
0 10 20
B 10 100 1,000
VANADIUM
35
FREQUENCY, IN PERCENT
0 5 10 15 20 25 30
B 10 100 500
YTTRIUM
92.8
FREQUENCY, IN PERCENT
0 1 2
B 200 1,000 5,000
ZINC
25
FREQUENCY, IN PERCENT
0 5 10 15 20
B 10 100 1,000 >1,000
ZIRCONIUM

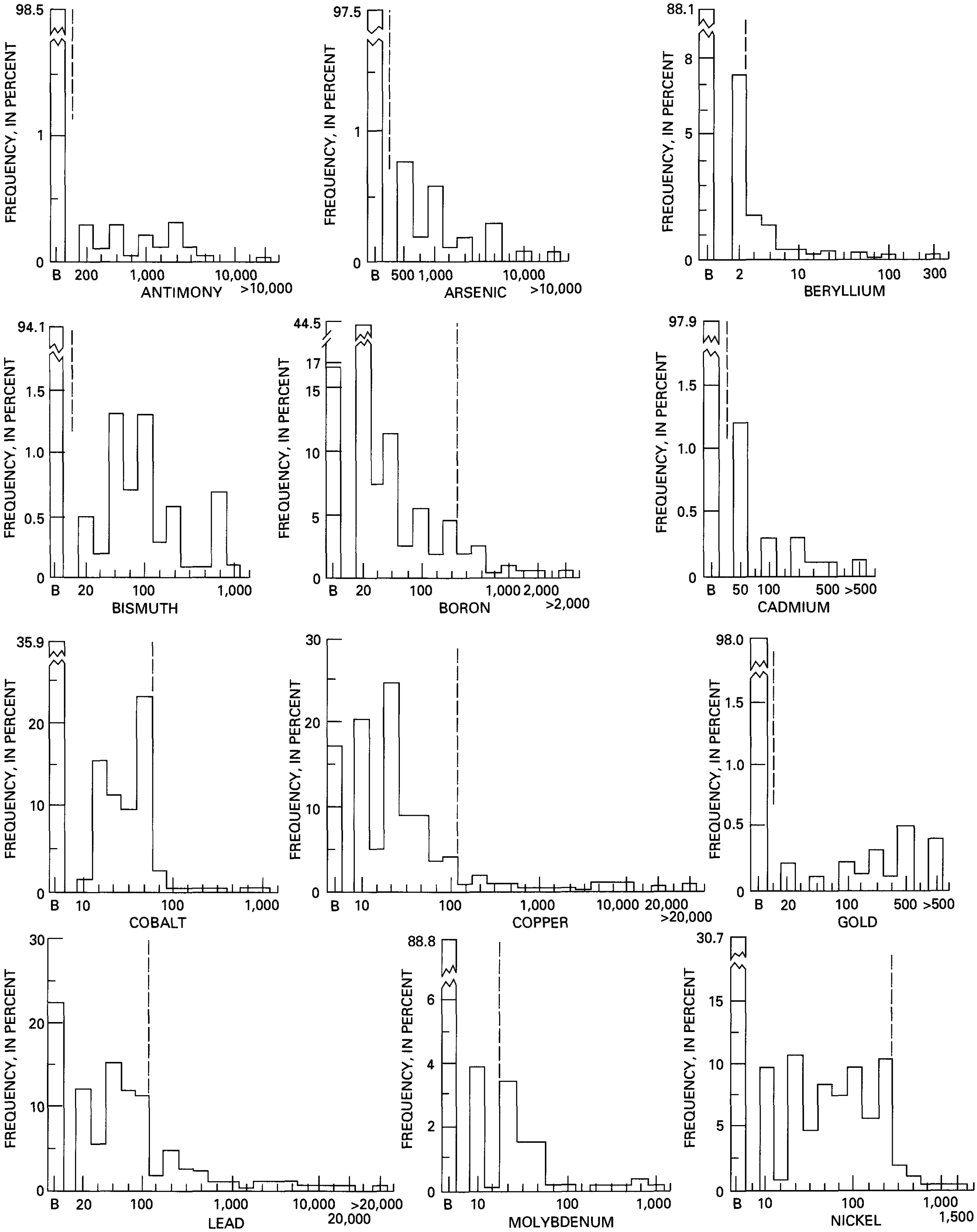
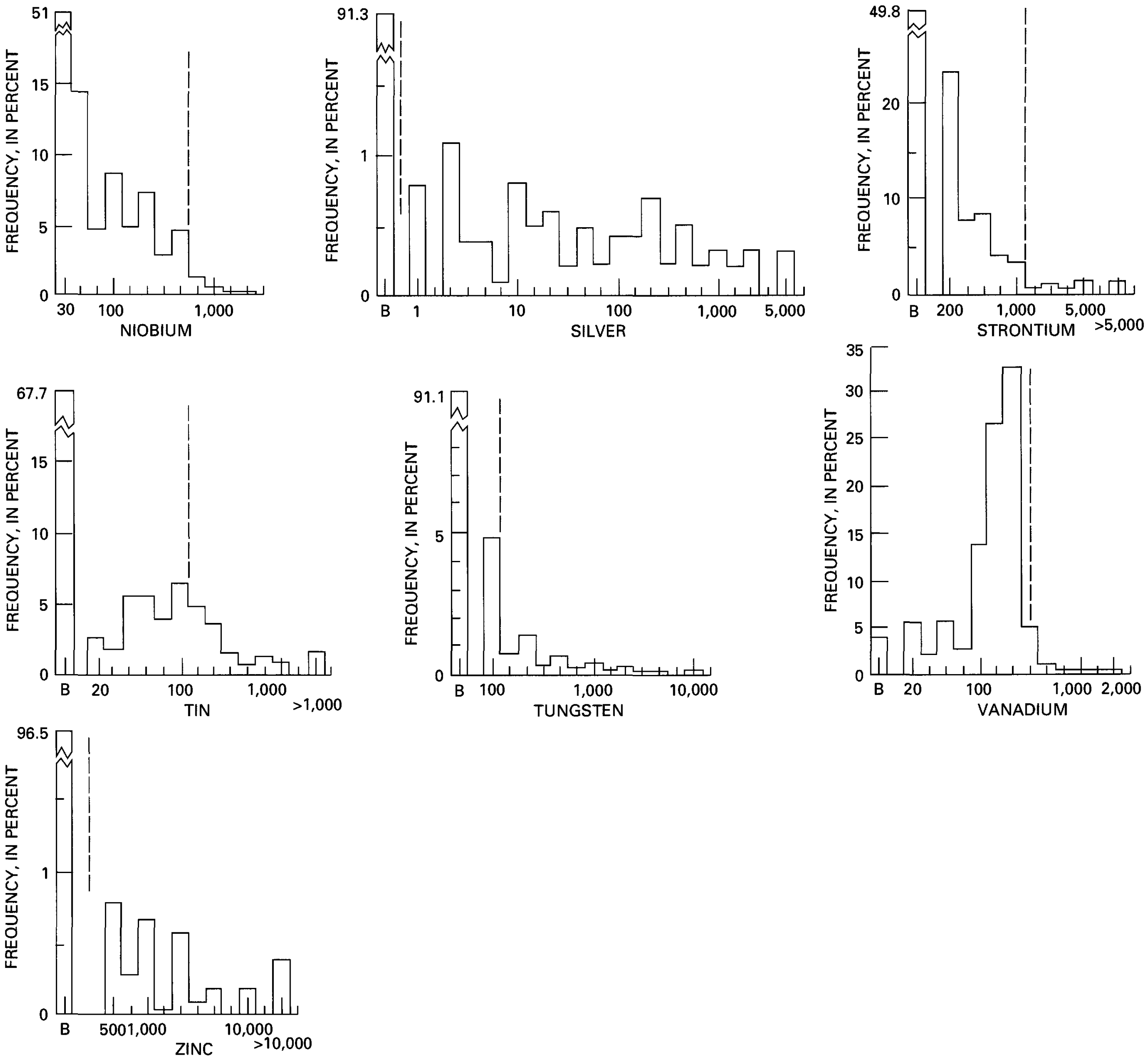


Figure 15 (above and facing page). Histograms for spectrographic analyses of nonmagnetic heavy-mineral-concentrate samples from Challis CUSMAP. All values reported in parts per million. Values to right of dashed line are considered anomalous. B, below limit of determination; >, greater than. N = 2,359.



70 ppm, and in basalt 150 ppm (Levinson, 1980). In a single data set covering an area with all three rock types, the basalt would have the highest concentration of nickel. Plotting those highest values on a map would result in a pattern that showed the extent of basalt. Granodiorite that was in fact enriched in nickel might not even appear—although if a cluster of high nickel concentrations 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.

Because the data were handled as two separate data sets, anomaly thresholds are not necessarily the same within and outside the two large primitive areas. This is a result of the process by which the thresholds 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 anomaly thresholds. A single anomalous sample is not considered significant; it may represent only variability resulting from sampling or analytical techniques. Clusters of anomalous

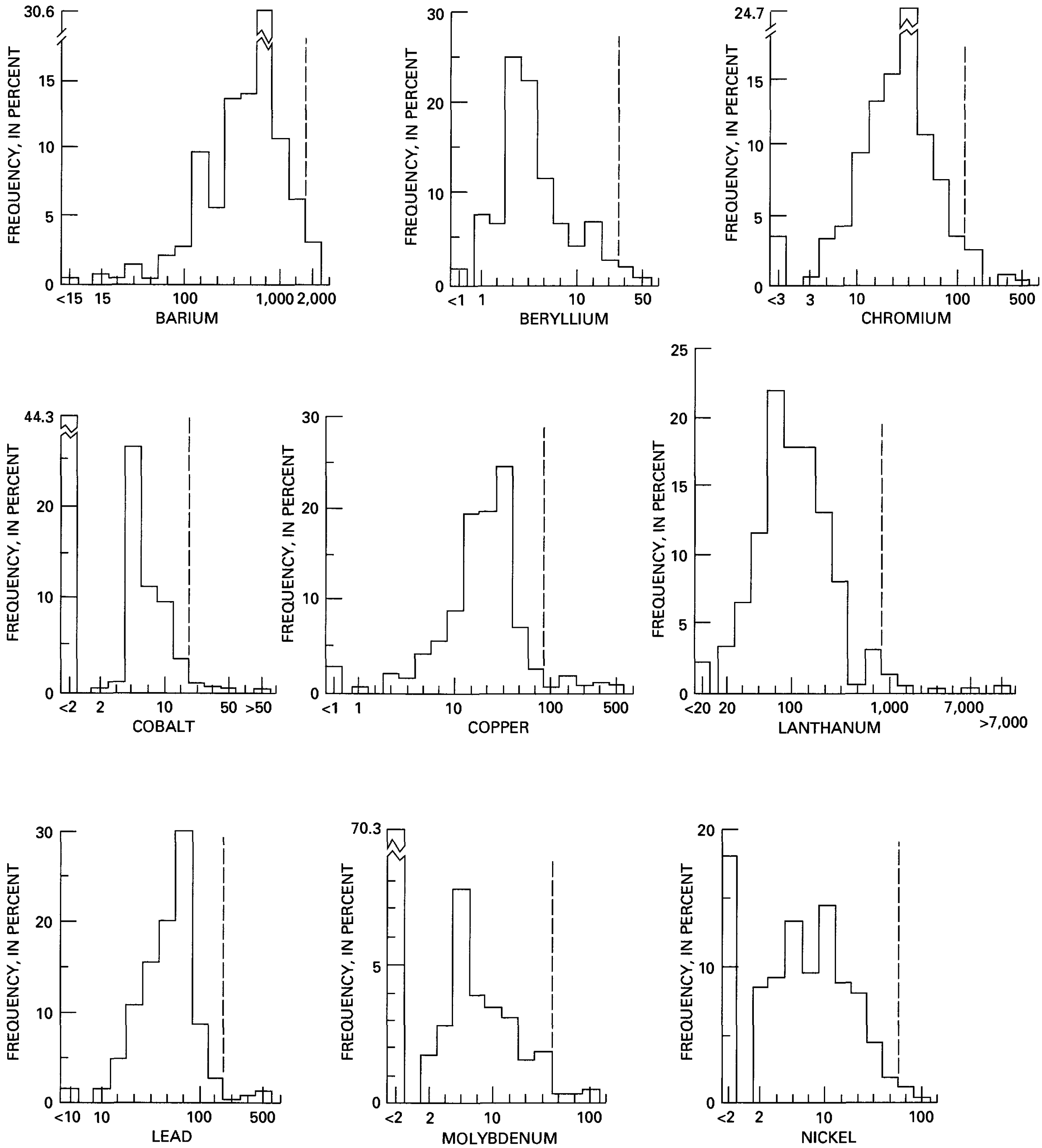
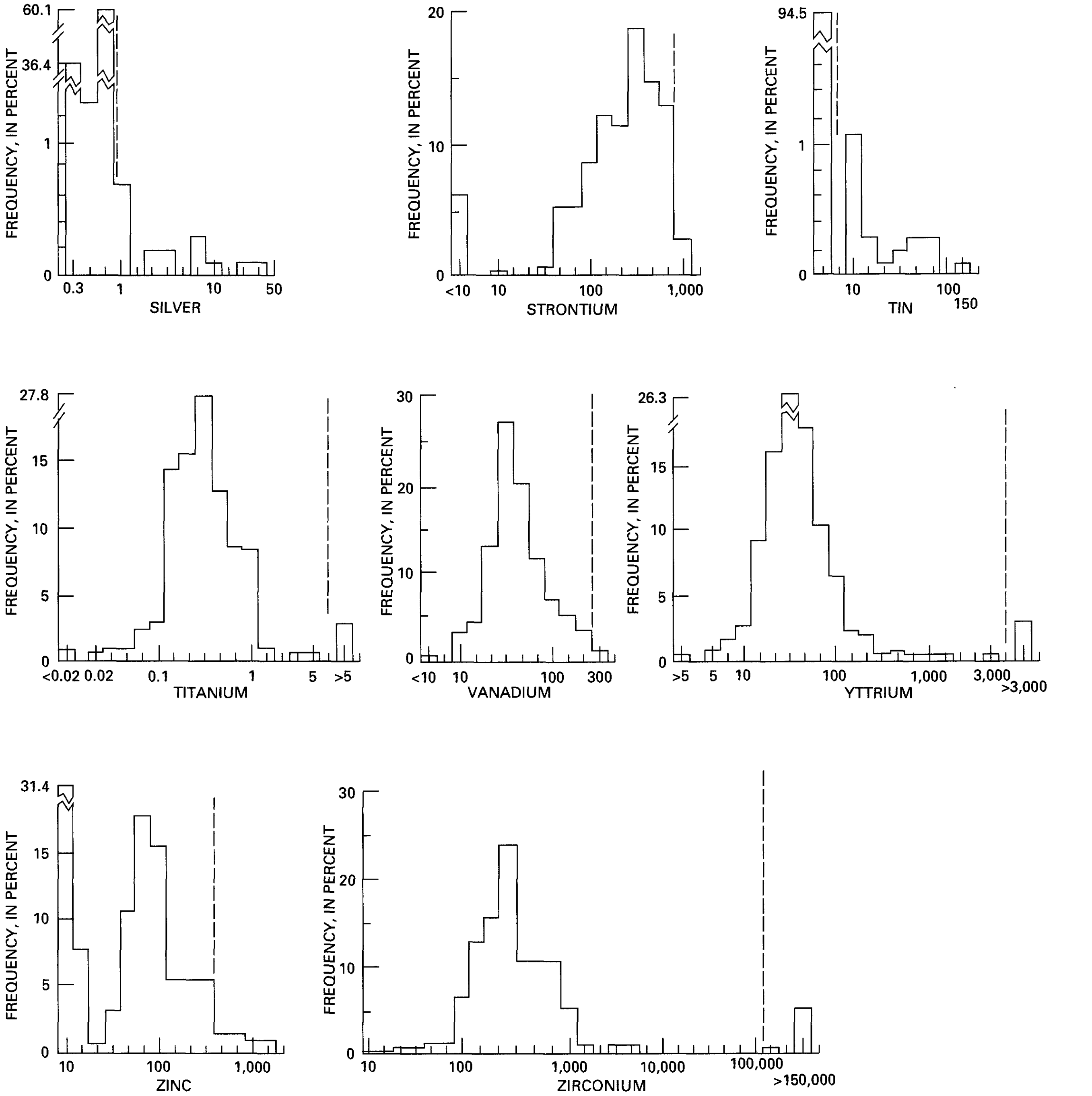


Figure 16 (above and facing page). Histograms for spectrographic analyses of stream-sediment samples from Sawtooth Primitive Area and Idaho Primitive Area. All values reported in parts per million, except titanium, which is in percent. Values to right of dashed line are considered anomalous. <, less than; >, greater than. N = 539.

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.

Figure 17 shows localities of anomalous amounts of gold in panned concentrates for the newly sampled areas of the quadrangle. Most of the sample localities fall within the trans-Challis fault system and many are in areas containing productive gold deposits. The locations shown along Johnson Creek (pl. 1) and the South Fork Salmon River (pl. 1), in the northwestern part of the quadrangle, are not closely associated with any major gold deposits. Mitchell and others (1981) showed 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).

The highest beryllium concentrations also are mostly within the trans-Challis fault system. Figure 18 shows that most of the anomalous samples are in the part of the trans-Challis fault system that traverses the Challis Volcanic Group. This may reflect the tendency of beryllium 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-stage beryllium-bearing fluids. The other important hosts for beryllium are the Idaho batholith and Sawtooth batholith, both of which contain beryllium-bearing pegmatites.

Anomalous concentrations of tungsten in the nonmagnetic fraction of the panned concentrates are unevenly dispersed in a northwest-trending zone (fig. 19). This trend appears to agree well with the distribution of tungsten mines and prospects, although lack of panned-concentrate samples from the primitive areas and the Sawtooth National Recreation Area precludes a complete comparison. This reflects only scheelite-bearing sources of tungsten because

Table 6. Anomaly thresholds for stream-sediment and heavy-mineral-concentrate samples from the Challis 1°×2° quadrangle, Idaho, and geochemical abundances for average granite and average shale.

[All values reported in parts per million, except titanium, which is in percent; --, no anomaly threshold was determined; >, greater than. Anomaly thresholds for stream sediments from the primitive areas are not the same as for stream sediments elsewhere in the quadrangle because the two sample sets were collected nearly 15 years apart by different individuals who used different sampling techniques and different methods of handling and processing the samples]

Element	Stream-sediment samples	Heavy-mineral concentrates	Stream sediments from 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).

wolframite and other tungsten minerals would be concentrated in the magnetic fraction. 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 distribution of stream-sediment samples containing anomalous concentrations of lead, zinc, and copper are shown in figure 20. Lead and zinc anomalies 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. 25), has been shown to be enriched in many metals (Fisher and May, 1983), and base-metal vein deposits are also known to occur in the area, and thus the anomalies are logical. The northwest-trending zone of lead-zinc anomalies is roughly coincident with the belt of tungsten anomalies 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 of lead-zinc anomalies, but copper alone is anomalously concentrated in the northeast corner of the quadrangle. This distribution suggests that copper is associated with Proterozoic metasedimentary rocks. Roof pendants in the Idaho batholith may account for the scattered distribution of copper anomalies in the western part of the area.

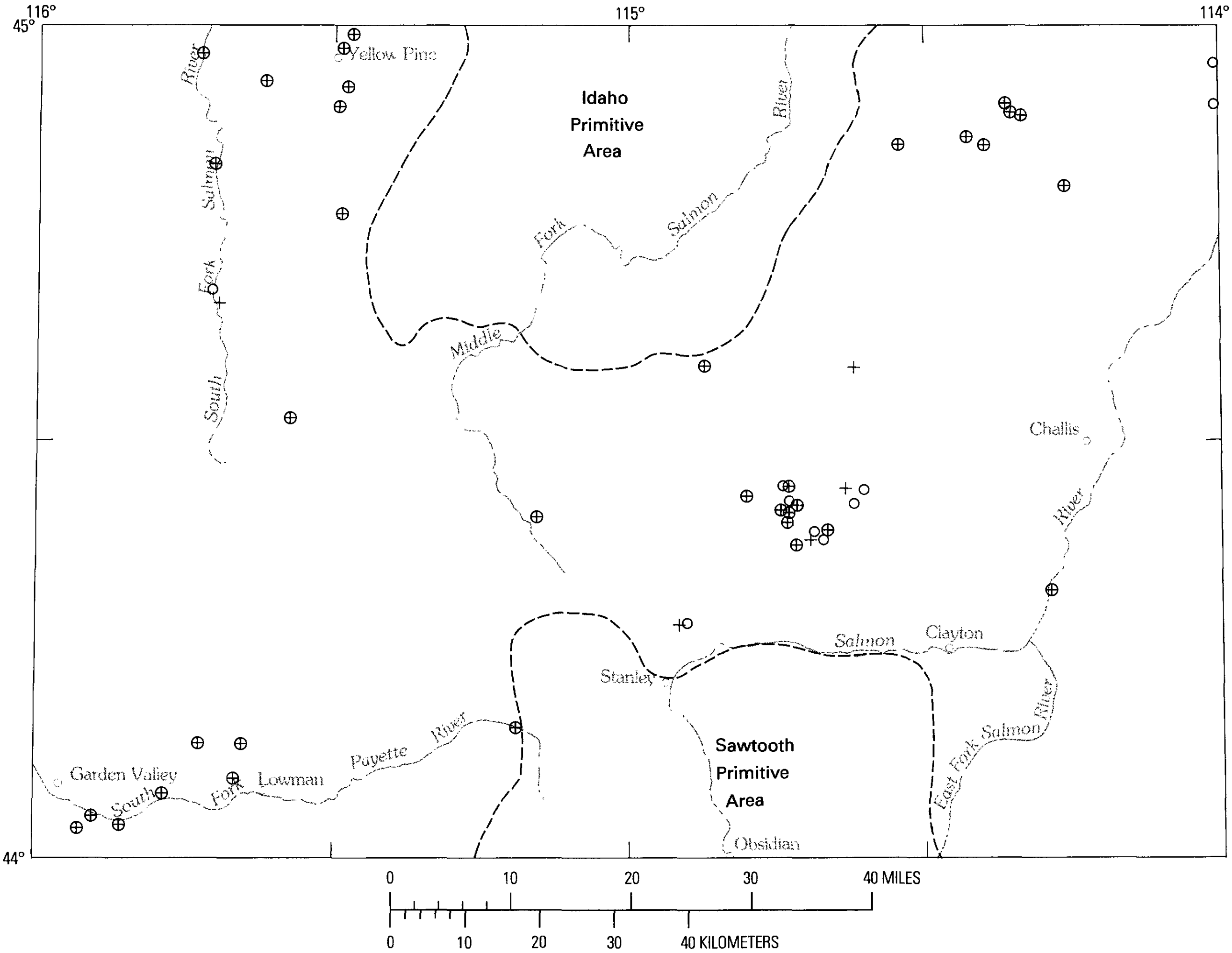
Figure 21 shows the distribution of anomalous concentrations of cobalt, chromium, nickel, scandium, and vanadium in stream sediments. Most of the points shown on the map fall within the Challis volcanic terrane and are in streams draining lower andesitic and dacitic units. This concentration appears 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 or in resource assessment. 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

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 comprises 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. 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 investigators.

SALMON RIVER ASSEMBLAGE

Fisher and May (1983) collected 257 rock samples from an area of about 40 sq mi to test the potential of the



EXPLANATION

○ **Gold > 20 grains observed in pan**

+ **Gold > 15 ppm in panned concentrates**

Figure 17. Distribution of gold in nonmagnetic heavy-mineral concentrates from the Challis 1°×2° quadrangle, Idaho. Dashed lines show boundaries of areas for which data are not available. >, greater than; ppm, parts per million.

Salmon River assemblage for syngenetic metallic ore deposits. These rocks are exposed in the south-central part of the quadrangle and are included in the black shale terrane (Hall and Hobbs, this volume, p. 25).

Rock-chip and grab samples were analyzed by semiquantitative spectrographic and atomic-absorption methods. Comparison with published reports of metal concentrations in black shale shows that the rocks sampled are enriched in several elements, chiefly silver, barium, copper, molybdenum, vanadium, and zinc. Other elements present in anomalous concentrations are arsenic, gold, boron, cadmium, lead, antimony, and tin. Fisher and May (1983) reported correlations among molybdenum, zinc, and vanadium and between silver and vanadium. They suggested that the apparently wide dispersal of anomalous metal concentrations may result from either original metal distribution, post-depositional introduction or redistribution of metals, or biased sampling.

IDAHO BATHOLITH

Geochemical and petrologic studies of the Atlanta lobe of the Idaho batholith help to define six major rock types: tonalite, hornblende-biotite granodiorite, porphyritic granodiorite, biotite granodiorite, muscovite-biotite granite, and leucocratic granite. Kiilsgaard and Bennett (this volume, p. 36) discuss the relation between these rock types and mineral deposits. Lewis and others (1985) showed that the tonalite has igneous-associated (I-type) (Chappell and White, 1974) mineral and chemical

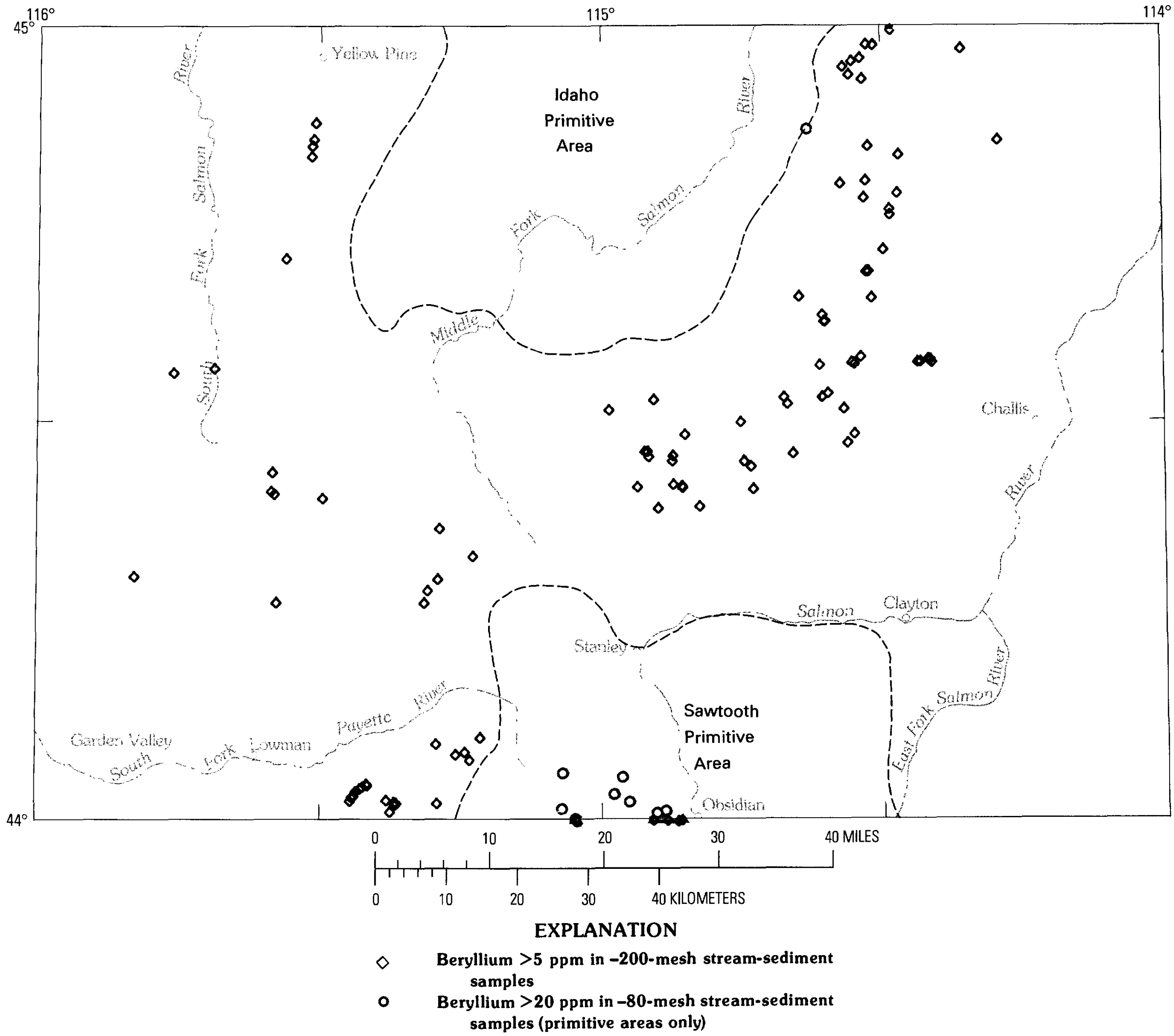


Figure 18. Distribution of beryllium in stream-sediment samples from the Challis 1°×2° quadrangle, Idaho. Dashed lines show boundaries of primitive areas. >, greater than; ppm, parts per million.

composition, the muscovite-biotite granite has many characteristics of sediment-associated (S-type) granite, and the biotite granodiorite has characteristics of both types of granite.

Lewis and others (1985) also reported a systematic variation in major-element chemistry of the batholith. Samples collected along a 7 mi traverse, 20 mi east of the west margin, showed 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 50 mi. Rocks along the east margin contain less SiO_2 and more CaO, MgO, and Al_2O_3 than do 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.

VAN HORN PEAK CAULDRON COMPLEX

Intrusive and extrusive calc-alkaline rocks of the Eocene Challis Volcanic Group, as exposed in the Van Horn Peak cauldron complex (fig. 2), range from andesite to rhyolite and have been subjected to a variety of post-consolidation alteration processes. Back (1982) used

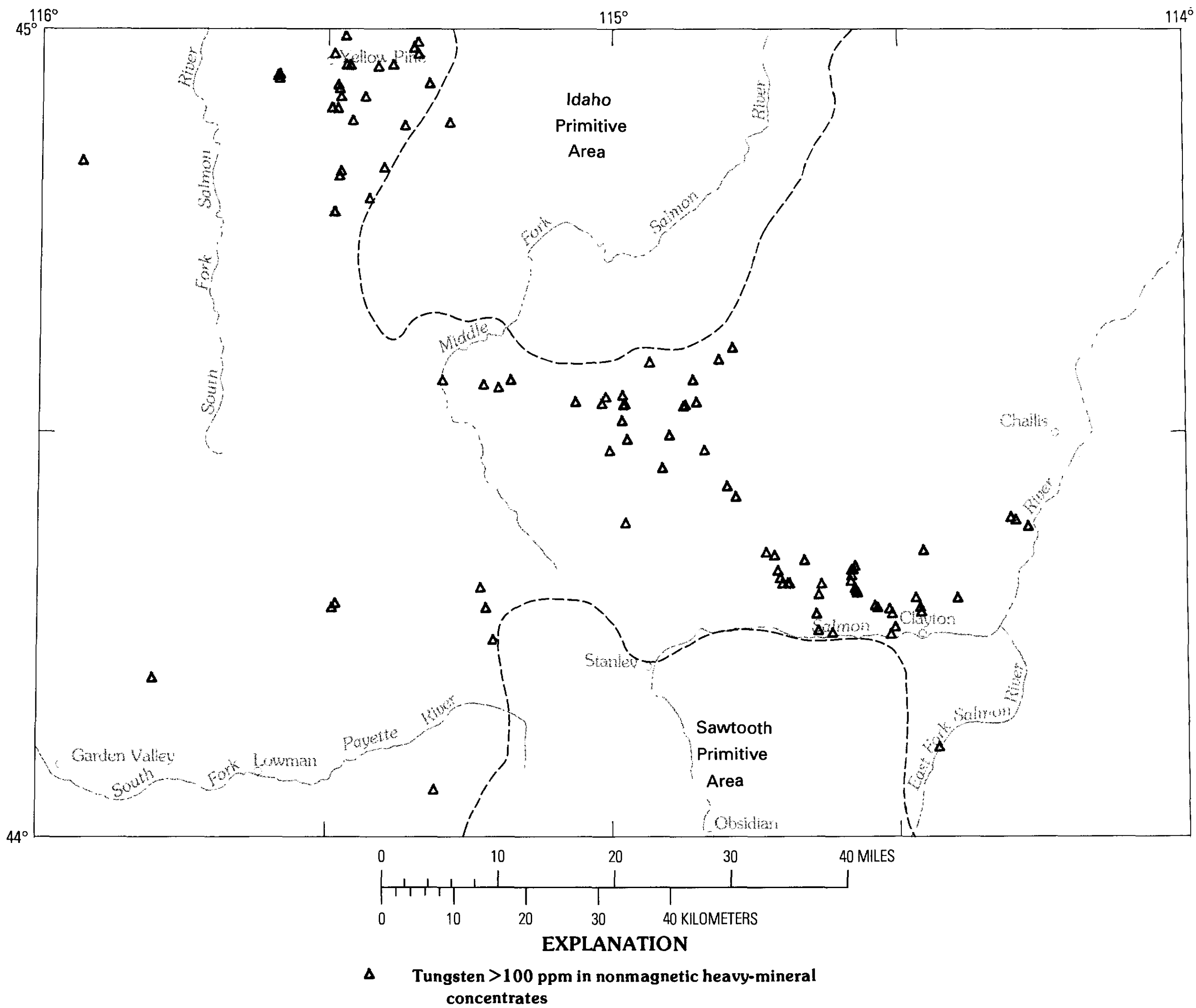


Figure 19. Distribution of tungsten in nonmagnetic heavy-mineral concentrates from the Challis 1°×2° quadrangle, Idaho. Dashed lines show boundaries of areas for which data are not available. >, greater than; ppm, parts per million.

petrologic and geochemical analyses to document similarities and differences among 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 (1982, p. 165) found that successive tuff layers 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 having similar silica content.

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 are along fractures and in vugs. Back concluded that these are products of low-temperature hydrothermal alteration and on this basis described at least two episodes of alteration: regional propylitic alteration throughout the cauldron complex and later, structurally controlled hydrothermal alteration.

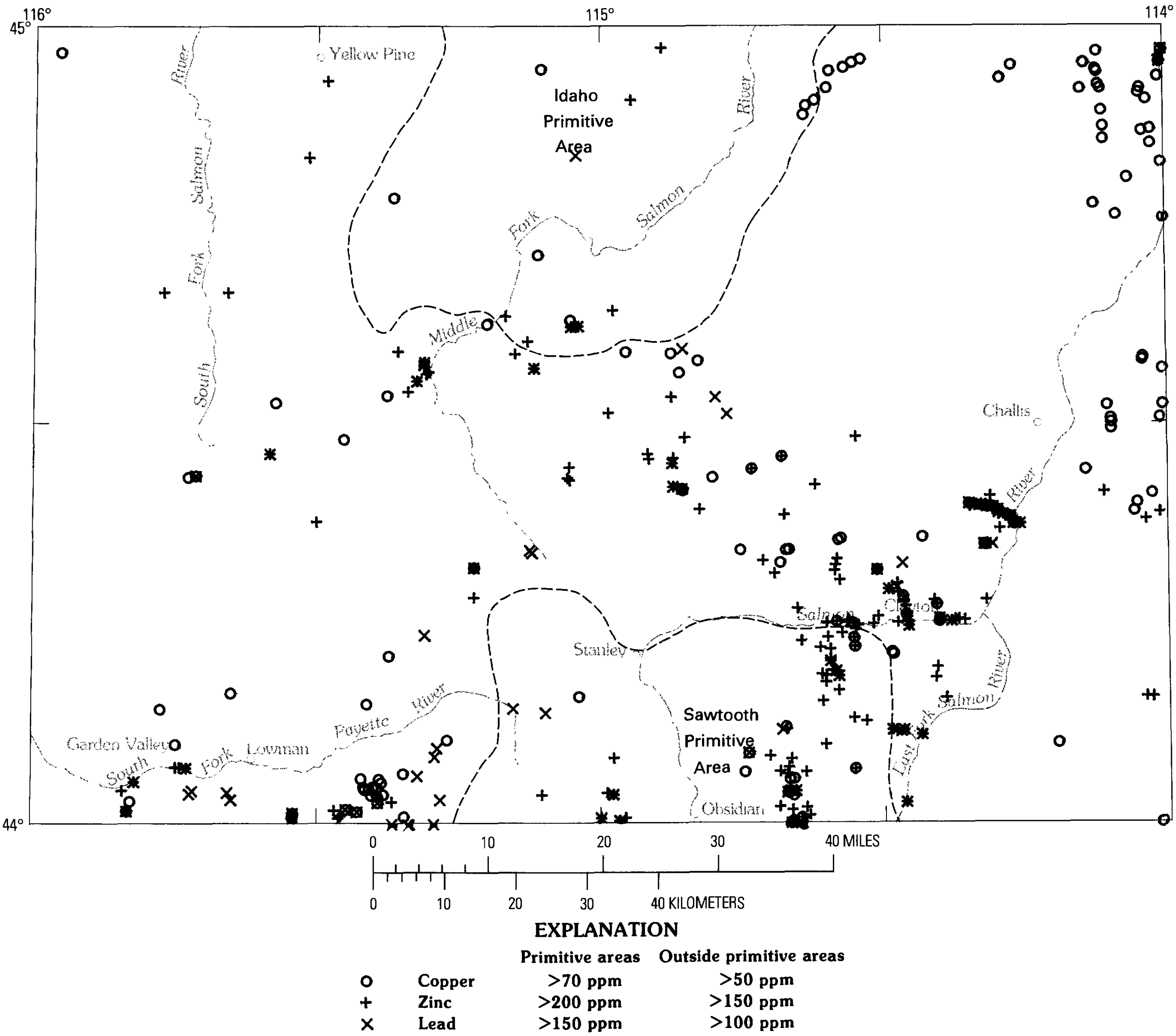


Figure 20. Distribution of lead, zinc, and copper in stream-sediment samples from the Challis 1°×2° quadrangle, Idaho. >, greater than; ppm, parts per million. Dashed lines show boundaries of primitive areas.

GOLDEN SUNBEAM MINE AREA

The Golden Sunbeam mine (pl. 1) is in 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 the Golden Sunbeam mine north to Mystery Creek (44°30′ N., 114°49′ W.) and China Creek (44°24′ N., 114°46′ W.). Foster and Cooley (1982) presented 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) reported that host rocks at the 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. 135).

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.), in the Yellow Pine mining district, by means of biogeochemical techniques (Leonard and Erdman, 1983; Erdman and others, 1985). The area had been prospected

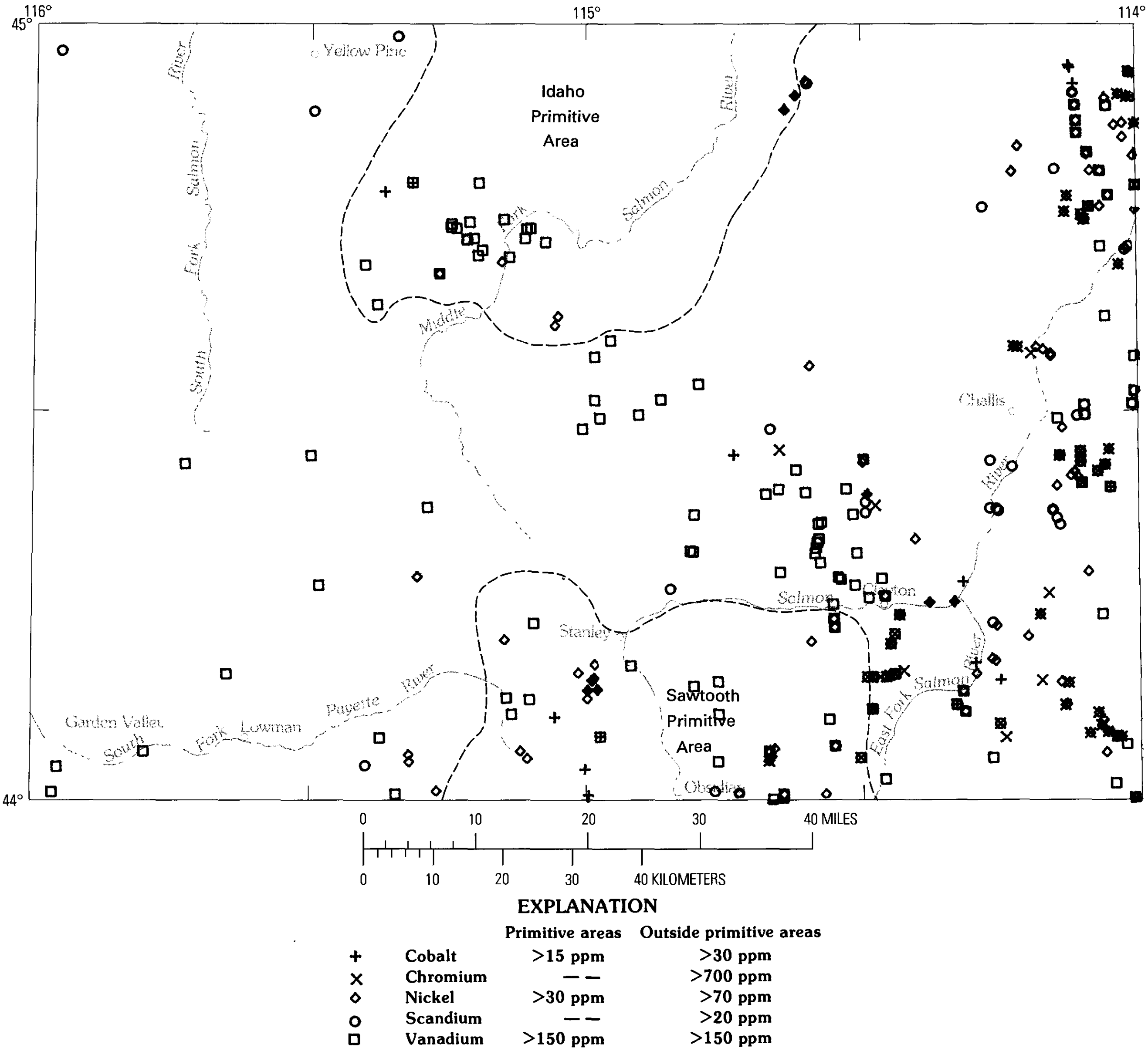


Figure 21. Distribution of cobalt, chromium, nickel, scandium, and vanadium in stream-sediment samples from the Challis 1°×2° quadrangle, Idaho. Dashed lines show boundaries of primitive areas. >, greater than; ppm, parts per million; --, no data available.

for gold and silver for more than 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 deposit 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 contains molybdenite, scheelite, and stibnite, in addition to sparse pyrrhotite and ubiquitous pyrite and arsenopyrite. It is surrounded by a large envelope of rock altered to clay minerals.

Soil and plant samples were collected at sites 600 ft apart over an area of 3,300 ft × 7,500 ft. Metal anomalies in the soils sampled were low, although a tungsten anomaly was located south of the stockwork. Metal anomalies in plant ash were high and above-median values occur over large areas. Most of these anomalies occur outside the stockwork, on either Quaternary valley fill or granodiorite containing inclusions of quartzite, biotite schist, and amphibolite. Analysis by instrumental neutron activation of Douglas-fir wood reduced to ash 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 gold anomalies were found in soil. 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 sandstone and conglomerate 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 the amounts found 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 Scintrex UA–3 uranium analyzer. Measured values of uranium in water were normalized, using measured conductivity values, to account for dissolved solids in the water. Values of uranium measured in bryophyte ash were normalized by ash weight percent to account for contamination by trapped sediments. Samples from three sites had anomalous normalized uranium values, both in water and in bryophytes. Shacklette and Erdman (1982) concluded 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 among bryophyte species; Shacklette and Erdman (1982, p. 235) stated 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) reported 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 basin of the North Fork 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 reported that for copper and cobalt the effects of mineralization on the metal content of mosses are greater than the effects of differences between moss species. They collected only one species at each sample site and found (1) similar concentrations between species and (2) large differences within the same species depending on whether or not the sample came from downstream of mineralized ground. These findings suggest that mosses as a group are 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 in table 7. 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 in table 7 is described and its resource potential discussed later in this report. The order of presentation is the same as table 7. 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, historically has been the major mining objective in the area and these deposits still attract 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 and alluvial 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 largest 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 rhyolite bodies offer attractive targets for large-tonnage, low-grade precious-metal deposits.

Pegmatites and miarolitic cavity deposits are restricted to the Idaho batholith and Eocene plutonic terranes. These deposits are not large producers and are of greater interest for their mineralogy 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 tungsten and large deposits of molybdenum.

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

Stratiform replacement deposits occur in the carbonate, black shale, and Challis volcanic terranes. Gold deposits in the Thunder Mountain cauldron complex (Challis volcanic 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 occur in the Proterozoic terrane. Little or no production from these deposits in the Challis quadrangle has been recorded, 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 for their rare earth and thorium content. 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 8. Table 9 lists the recorded post-1900 placer production of gold and silver. The pre-1901 placer production of gold is shown in table 10, the latter estimates, at best, because much of the pre-1901 production was not recorded and, in general, these production figures are probably low.

Figures 22 and 23 summarize the data from table 8. 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 terrane and the Proterozoic 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.

Table 7. Classification of mineral deposit types for the Challis 1°×2° quadrangle, Idaho.

[Known mineral deposit types are those types present in the Challis quadrangle and in most cases have been (or are being) mined. Postulated mineral deposits are those types not known to occur in the Challis quadrangle; however, geologic features commonly associated with these deposit types are present in the quadrangle]

KNOWN MINERAL DEPOSIT TYPES
Veins:
Precious metals
Mixed base and precious metals
Lead-silver-zinc-antimony-tin
Fluorspar
Uranium
Tungsten
Manganese
Semiprecious opal
Stockworks:
Cretaceous molybdenum
Tertiary molybdenum
High-level, rhyolite-hosted precious metals
Disseminations:
Graphite in metamorphic rocks
Pegmatites:
Mica, feldspar, columbite, and rare-mineral pegmatites
Piezoelectric quartz crystal-bearing pegmatites
Miarolitic cavities:
Semiprecious gemstone
Skarns:
Polymetallic
Replacement deposits:
Rare-earth elements
Base and precious metals
Mercury
Zeolites in tuffaceous rocks
Stratiform:
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 argillite and micritic limestone
Cobalt-copper deposits
Placers:
Gold
Radioactive black sand

KNOWN MINERAL DEPOSIT TYPES—CONTINUED
Rock products:
Quartzite (flagstone)
Granite (building stone)
Volcanic tuff (building stone)
Sand and gravel

POSTULATED MINERAL DEPOSIT TYPES
Opalite-type mercury veins
Uranium in sedimentary rocks in contact zones with granitic rocks
Vein and replacement alunite deposits
Silver deposits in caldera-filling lake sediments
Carlin-type carbonate-replacement gold deposits
Stratabound copper-silver deposits in Proterozoic quartzites

The production of silver shows a somewhat different pattern than that of gold (figs. 22 and 23). Mines within Paleozoic sedimentary rocks, the black shale and carbonate terranes, have produced the bulk of the silver from the quadrangle. The combined total production of silver from the igneous rock terranes (Idaho batholith, Challis volcanic, and Eocene plutonic terranes) is about one quarter of that produced from deposits hosted by Paleozoic rocks. Production figures thus suggest that gold and lesser amounts of silver are associated with igneous rock terranes whereas 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 22 and 23. Several patterns are obvious: first, the greatest production of base metals has come from mines in terranes containing sedimentary rocks (black shale and carbonate rocks); 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 terranes is insignificant. It should be noted that most of the lead and nearly all of the zinc shown for the Idaho batholith terrane was produced from a single mine, the Deadwood/Hall–Interstate mine. Ore at this mine occurs as veins in roof 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. 143; Kiilsgaard and Bennett, this volume, p. 40).

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. Nevertheless, figures 22 and 23 clearly indicate that zinc is also a major component of the ores from the carbonate, black shale, and Idaho batholith terranes.

Table 8. Production of base and precious metals from the Challis 1°×2° quadrangle, Idaho.

[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, 1937a,b), Treves and Melear (1953), Tschanz and Kiilsgaard (1986), Umpleby (1913a,b), and Van Noy and others (1986). --, 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
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

Table 8. Production of base and precious metals from the Challis 1°×2° quadrangle, Idaho—Continued.

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
		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	--
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	--

Table 8. Production of base and precious metals from the Challis 1°×2° quadrangle, Idaho—Continued.

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
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
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	--	--	--

Table 8. Production of base and precious metals from the Challis 1°×2° quadrangle, Idaho—Continued.

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
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
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
District uncertain					
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	--	--	--

Table 8. Production of base and precious metals from the Challis 1°×2° quadrangle, Idaho—Continued.

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
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	--	--	--
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	--
Sunbeam	217	2,490	--	--	--
Sunset	5	4	--	--	--

Table 8. Production of base and precious metals from the Challis 1°×2° quadrangle, Idaho—Continued.

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
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	--	--	--
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	--	--	--

Table 8. Production of base and precious metals from the Challis 1°×2° quadrangle, Idaho—Continued.

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
Other production (1934-48)	--	98	3,375	--	--
Recorded total	3,734	6,920	28,954	24,215	4,115
Calculated (pre-1900) total	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
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	--	--	--

Table 8. Production of base and precious metals from the Challis 1°×2° quadrangle, Idaho—Continued.

Mine name	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)
		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 11 shows selected metal ratios in six bedrock lithologic terranes in the quadrangle. Figures 24 and 25 show the production of gold, silver, copper, and lead from four of the six terranes. Mines in the Proterozoic terrane and the Eocene plutonic terrane were not plotted on figures 24 and 25 because only a few mines produced significant amounts of ore. In table 11 and figures 24 and 25 only post-1900 production data were used because of the uncertainty in the pre-1901 production estimates. Only mines producing greater than 100 oz of gold or silver or 100 lb of copper or lead were plotted in figures 24 and 25. The ratios (table 11) and the distribution of points showing production data (figs. 24 and 25) suggest that each terrane has a characteristic suite of metals.

Metals in the carbonate terrane correlate well with one another (fig. 24). Silver was by far the major precious metal produced from mines in the carbonate terrane. Gold is not a common constituent of the ores; only two mines (Clayton Silver and Red Bird) have produced greater than 100 oz of gold. Metal ratios (table 11) indicate that mines in the carbonate terrane produce nearly 3,000 oz of silver for each 1 oz of gold. All but five of the productive mines record more than 1,000 oz of silver production. Silver is also highly correlated with lead and copper (fig. 24), approximately 14 lb of lead and 0.25 lb of copper being produced for each 1 oz of silver (table 11).

Gold also is not common in the black shale terrane; only four mines have produced more than 10 oz and only one mine (Ramshorn) has produced more than 100 oz. In contrast, all but four of the mines in the black shale terrane have produced at least 100 oz of silver. Silver is highly correlated with both lead and copper, the mines producing approximately 1 oz of silver for each 1 lb of copper and every 6 lb of lead.

In the Idaho batholith and Challis volcanic terranes correlation coefficients between metals are generally low. Only gold-silver in the Challis volcanic terrane and silver-copper and copper-lead in the Idaho batholith terrane have correlation coefficients greater than 0.5 (fig. 25). The ratio of gold to silver produced is nearly the same in the Idaho batholith and Challis volcanic terranes, about 7 oz of silver having been produced for each 1 oz of gold. Mines in the Idaho batholith have higher ratios of base to precious metals than do the mines in the Challis volcanic terrane.

Only five mines in the Eocene plutonic terrane have produced more than 100 oz of gold or silver and only three mines have recorded a production of more than 100 lb of copper or lead. Ore from the productive mines yielded about 1.5 oz of silver for each 1 oz of gold and about 60 lb of lead for each 1 lb of copper (table 11).

In the Proterozoic terrane only eight mines recorded production of greater than 100 oz of silver or 100 lb of lead. The ores yielded about 2 oz of silver for each 1 oz of gold and slightly less than 1 lb of lead for each 1 lb of copper (table 11).

The characteristic metal assemblages for productive mines in the six bedrock geologic terranes in the quadrangle, as shown by the total amounts of metals produced (table 8, figs. 22 and 23) and by metal ratios in ores (table 11, figs. 24 and 25), are shown in figure 26. For example, in the Challis volcanic terrane, ores from the productive mines characteristically contain silver, with lesser amounts of gold. Copper and lead may or may not be present in the ore. Where present, lead is generally more common than copper. In contrast, mines in the black shale terrane are characterized by ores that are rich in lead and contain lesser amounts of silver and copper. They contain very little gold.

Table 9. Post-1900 placer gold and silver production, Challis 1°×2° quadrangle, Idaho.

[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,b)]

Mining district	Gold (oz)	Silver (oz)
Boise County:		
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:		
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:		
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:		
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

RESOURCE ASSESSMENT METHOD

The mineral resources of the Challis quadrangle were assessed on the basis of information available as of December 31, 1985, by 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 constituent in evaluating mineral resources. This approach is subjective

Table 10. Pre-1901 placer gold production, Challis 1°×2° quadrangle, Idaho.

[Names in parentheses are other names used for the given district. Data from Cater and others (1973), Choate (1962), Umpleby (1913b), and Umpleby and Livingston (1920)]

Mining district	Dollars (reported)	Ounces gold (calculated)
Custer County:		
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:		
Thunder Mountain (Dewey)	40,000	1,935
Challis quadrangle total	1,700,000	82,245

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 terms and concepts in mineral resource assessment. Resources are 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, the term "resource" has no implication for profitability or technologic feasibility. **Reserves** are one category of resource, specifically those resources whose extent and grade are known to some degree and which are known with reasonable certainty to be economically

Table 11. Selected metal ratios in ores produced from lithologic terranes in the Challis 1°×2° quadrangle, Idaho.

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

Metals	Proterozoic terrane	Carbonate terrane	Black shale terrane	Idaho batholith terrane	Challis volcanic terrane	Eocene plutonic terrane
Au:Ag	1:1.9	1:2,900	1:19,600	1:6.9	1:7	1:1.4
Au:Cu	1:7.8	1:593	1:19,100	1:5.5	1:0.3	1:0.4
Au:Pb	1:6.5	1:40,000	1:112,600	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

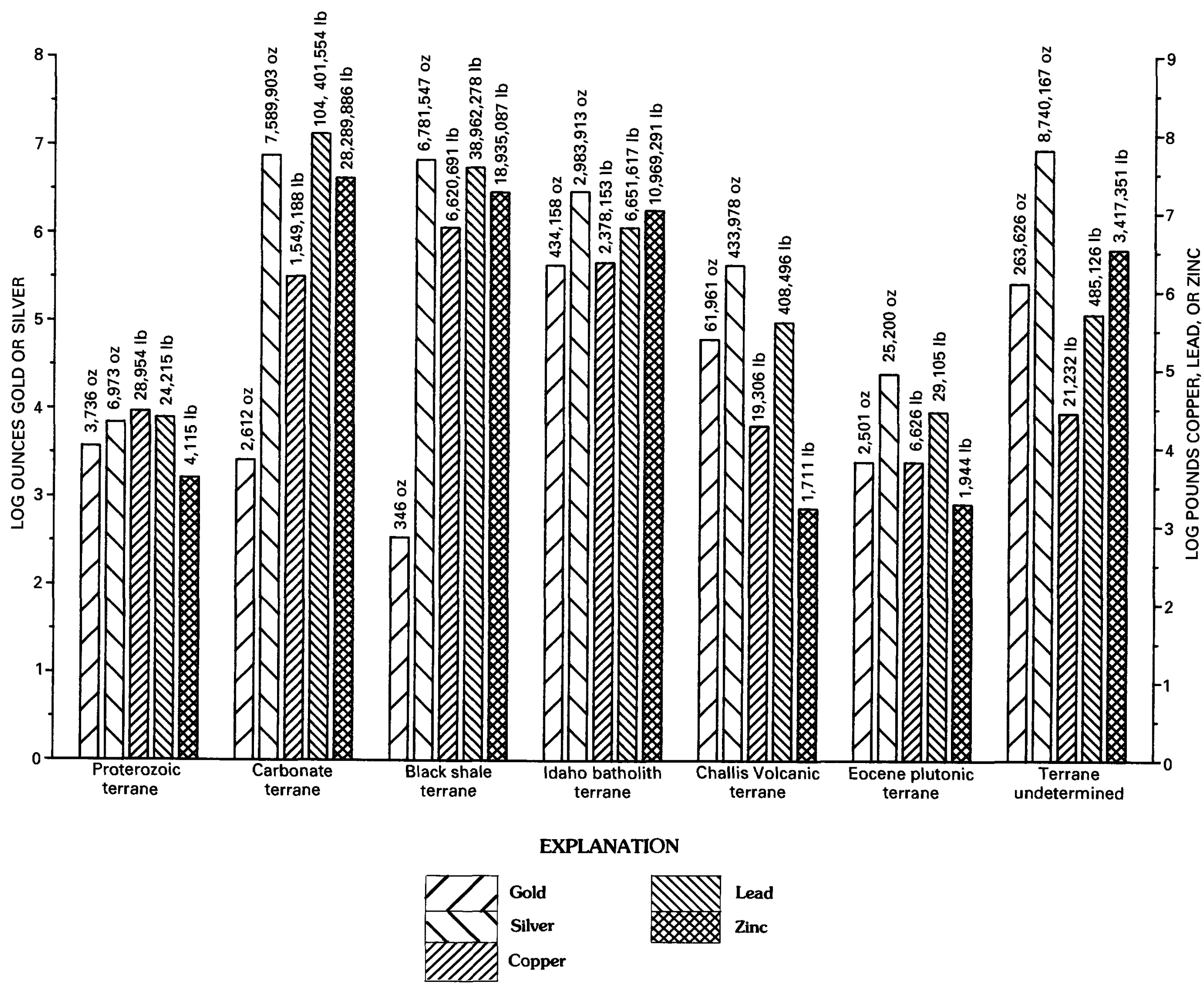


Figure 22. Histograms for total amounts of base and precious metals produced from each lithologic terrane in the Challis 1°×2° quadrangle, Idaho.

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 if 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 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). Reserves, conditional resources, hypothetical resources, and speculative resources together constitute the total resources 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 quadrangle, Missouri, 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)

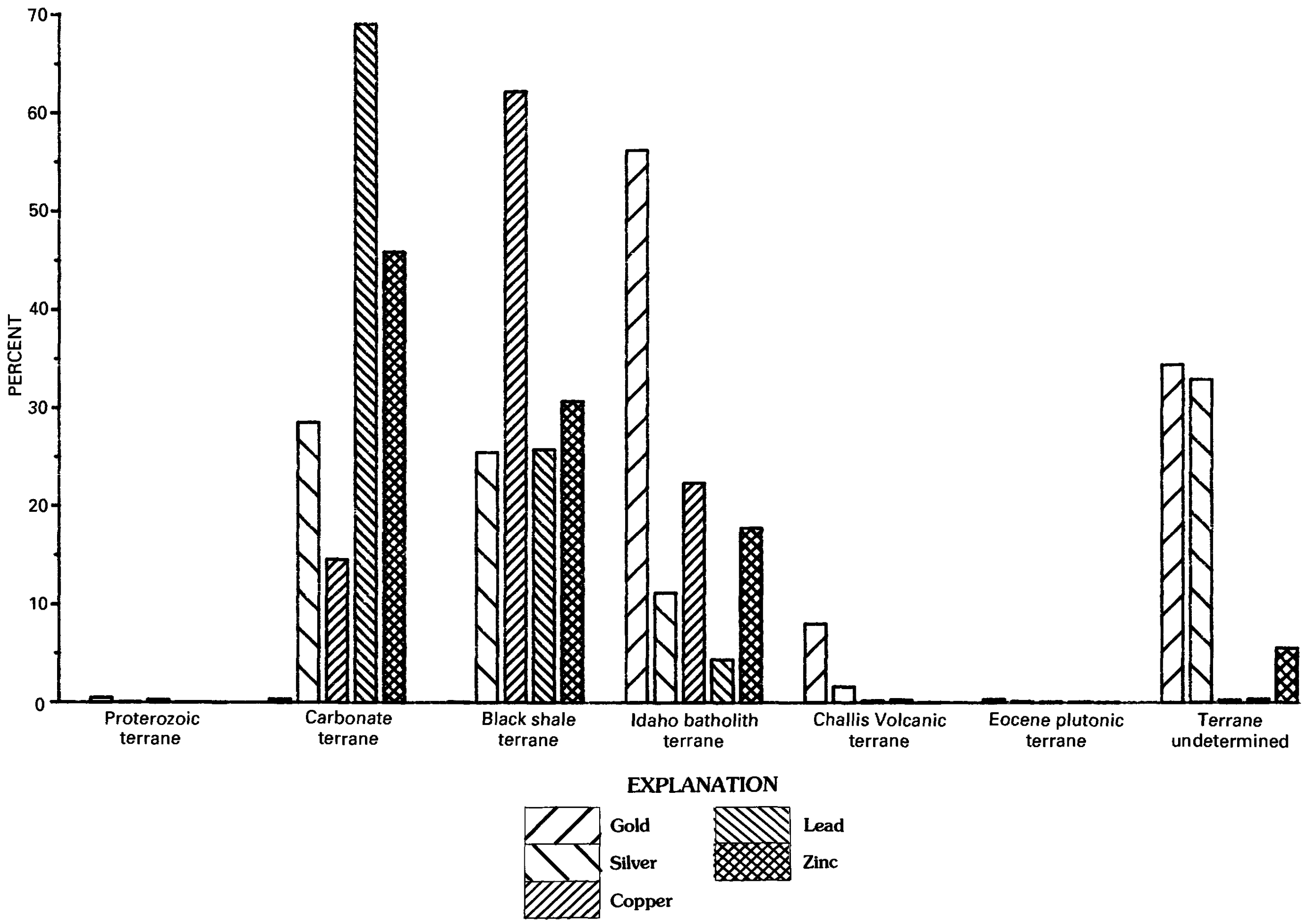


Figure 23. Histograms for percentages of base and precious metals produced from each lithologic terrane in the Challis 1°×2° quadrangle, Idaho.

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) 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)

In some instances an assignment of no mineral resource potential for a **particular ore deposit type** has been given to specific areas within the Challis quadrangle. In these cases the occurrence of the particular ore deposit

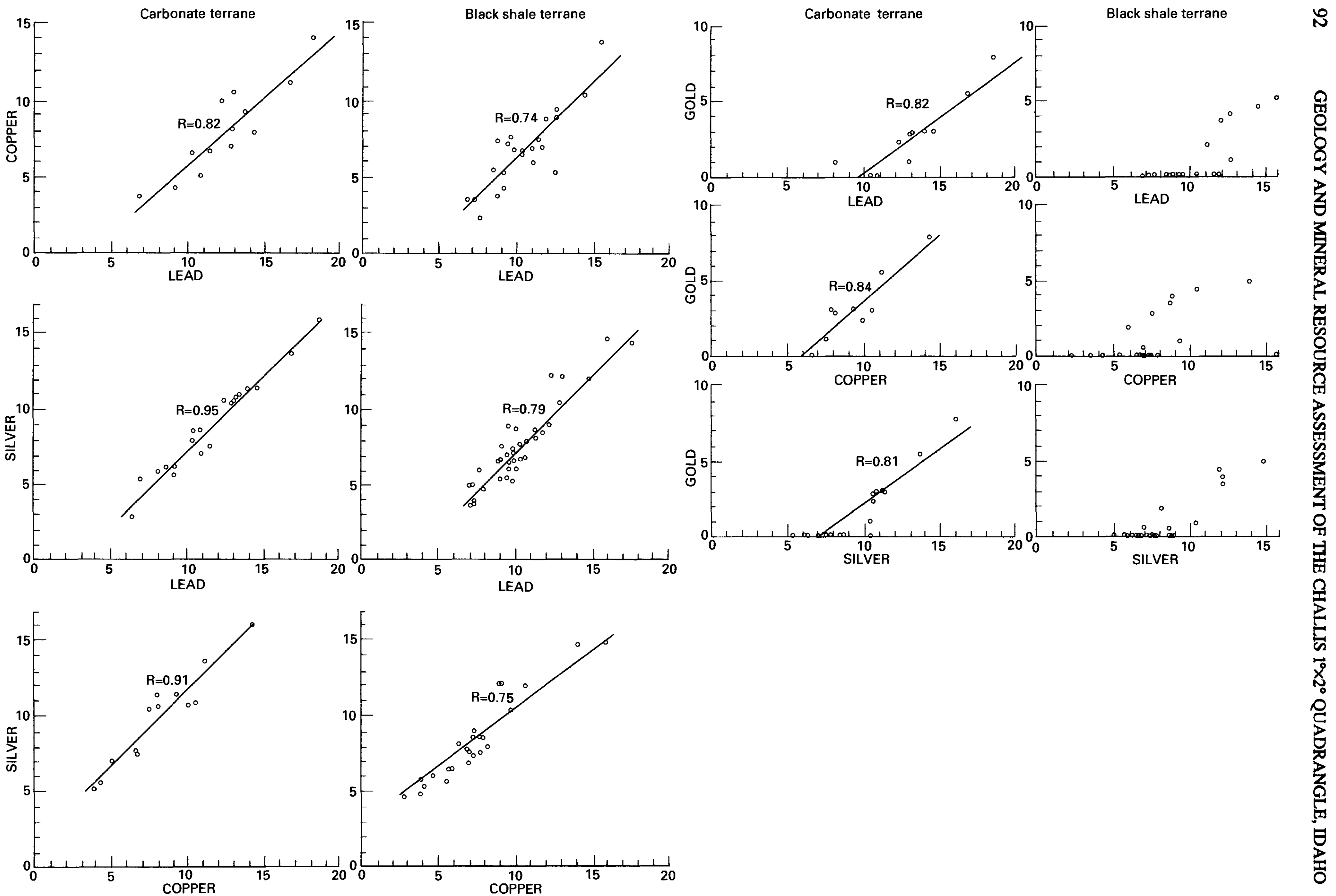


Figure 24. Correlation diagrams for gold, silver, copper, and lead in the carbonate and black shale terranes, Challis 1°×2° quadrangle, Idaho. Values plotted are the natural logarithms of the total amount of metal produced from each mine in the two terranes. Gold and silver values are in ounces; copper and lead values are in pounds. Only mines that produced more than 100 oz of gold or silver or 100 lb of copper or lead were plotted. Least-square regression lines were drawn only for those diagrams showing a correlation coefficient (R) greater than 0.5.

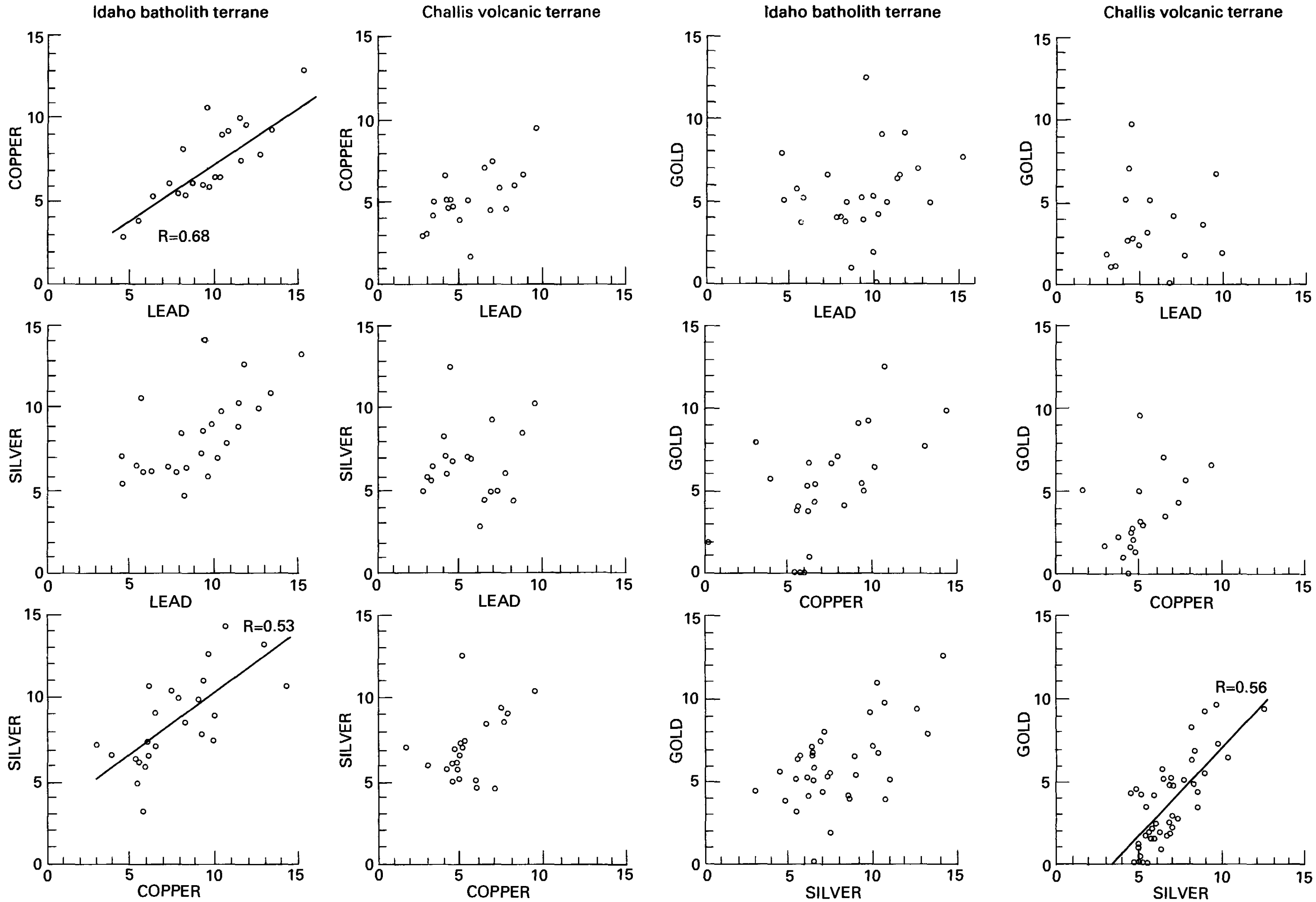


Figure 25. Correlation diagrams for gold, silver, copper, and lead in the Idaho batholith and Challis volcanic terranes, Challis 1°×2°quadrangle, Idaho. Values plotted are the natural logarithms of the total amount of metal produced from each mine in the two terranes. Gold and silver values are in ounces; copper and lead values are in pounds. Only mines that produced more than 100 oz of gold or silver or 100 lb of copper or lead were plotted. Least-square regression lines were drawn only for those diagrams showing a correlation coefficient (R) greater than 0.5.

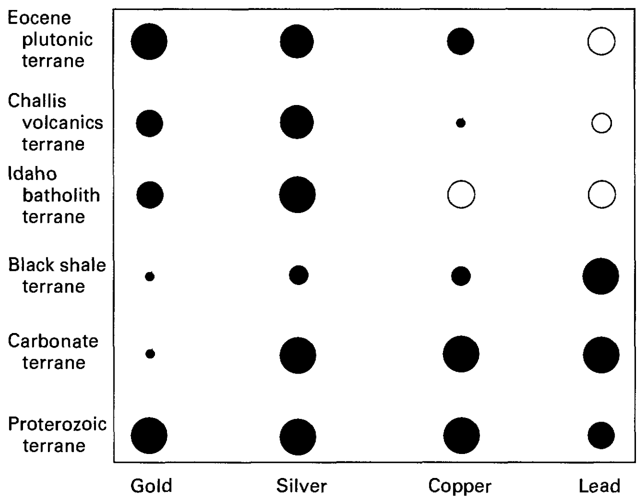


Figure 26. Metal assemblages for productive mines grouped according to lithologic terrane, Challis 1°×2° quadrangle, Idaho. Filled symbol indicates metal is invariably present. Open symbol indicates metal may be present or absent. Size of symbol indicates relative abundance of metal within each terrane.

type is dependent on the presence of a specific lithology. Known absence of the required rock type precludes the occurrence of the ore deposit. For example, the occurrence of stratabound, syngenetic cobalt-copper deposits requires the presence of sedimentary or metasedimentary rocks. In areas where these rocks are not present there is no possibility of discovering a stratabound, syngenetic cobalt-copper ore deposit.

Our method requires eight sequential steps for the assessment of each type of mineral deposit:

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 and define the recognition criteria for each deposit type.
5. Divide the criteria into diagnostic and permissive, following the definitions above.
6. Delineate areas 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 on the basis of their scores and on subjective weighting of geologic knowledge and experience.

Each of these steps is described below.

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, 1992, in pocket). Preliminary findings of the studies were presented in McIntyre (1985). The mineralization history of each terrane 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 mineral deposits in each terrane were determined by field studies. Mineral deposits in the Challis quadrangle 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 member of the project. These field observations, along with published and unpublished data, were used to describe the types of ore deposits. The descriptions include the following kinds of information wherever they were 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, character of contacts, shape, tonnage and grade 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 than on other deposits.

From the deposit descriptions, recognition criteria were defined for each deposit type. These criteria are based on, and 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 present could then be readily identified.

Areas in which diagnostic and permissive criteria were present were then scored as follows: widespread presence of a criterion was assigned a value of 1, known absence of a criterion was assigned a value of –1, and a lack of sufficient information to determine the presence or absence of the criterion was assigned a value of 0. 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 type of ore deposit. In many cases, estimates of grade, tonnage, or value were not made for types of ore deposits, areas, or individual commodities because of the lack of adequate data from drilling, mining, or sampling.

VEIN DEPOSITS

PRECIOUS-METAL VEINS

By Frederick S. Fisher, Thor H. Kiilsgaard, Kathleen M. Johnson, and Earl H. Bennett[6]

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 economic value, 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 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 12. 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 orebody characteristics. The ore bodies have limited vertical extent; the richer parts are higher in the vein and the ore minerals are less concentrated 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 southwestern part of the quadrangle strike northeast, parallel to the structures that define the trans-Challis fault system. In the central and northeastern parts of the quadrangle, some veins strike northeast, but many follow secondary faults of diverse strike.

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 48–45 m.y. (Kiilsgaard and Bennett, this volume, p. 44). 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 Payette River, yielded fission-track ages for zircon of 29.3±1.7 m.y. (Paul 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 in the Boise Basin are cut by precious-metal veins; also in the Boise Basin, some precious-metal veins are cut by rhyolite dikes (Ballard, 1924). These cross-cutting relations suggest 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 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 ft or more thick.

Shape.—Lenses, pods, planar veins, and aggregates of veinlets 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, one wall being 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 having 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 the 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 12); 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 12). 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;

[6]Idaho Geological Survey.

Table 12. Metals produced from precious-metal veins, through 1984, Challis 1°×2° quadrangle, Idaho.

[Includes properties that have produced more than 100 oz of gold or 1,000 oz of silver. Sources of data: Anderson (1949); Anderson and Rasor (1934); Choate (1962); Ross (1934b); Van Noy and others (1986); Umpleby (1913a,b); and unpublished records of U.S. Bureau of Mines, Spokane, Wash.; --, no data]

Mine name	Gold (oz)	Silver (oz)	Copper[1] (lbs)	Lead[1] (lbs)	Zinc[1] (lbs)	Pre-1900 production (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	--	--	--	--
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	--	--

Table 12. Metals produced from precious-metal veins, through 1984, Challis 1°×2° quadrangle, Idaho—Continued.

Mine name	Gold (oz)	Silver (oz)	Copper[1] (lbs)	Lead[1] (lbs)	Zinc[1] (lbs)	Pre-1900 production (dollars)
			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. Producers of ore and concentrates that contained zinc were penalized at the smelter.

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 (Ballard, 1924; Anderson and Rasor, 1934; Ross, 1937b; Anderson, 1947, 1949). 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 predominant gangue mineral and the guide to ore at most deposits. It ranges from cryptocrystalline to coarse, the finer grained quartz being along the vein walls in many places and the coarser quartz, sometimes having a comb structure, in the central parts of the vein. Older quartz tends to be gray to milky in color, whereas younger quartz is clear and vitreous. Clear quartz commonly 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 recovered as by-products.

Character of ore:

Ore minerals tend to be discontinuous in the vein. They form clustered bunches or lenses, in some places present 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 1 in. 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 many cases, altered barren rock can be distinguished from ore only by assay.

Weathering products:

Weathering 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 containing 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:

Host rocks are principally Tertiary and Cretaceous igneous rocks; deposits are also found in Proterozoic 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) 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 the most productive parts of certain Boise Basin veins was 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 Kiilsgaard, 1986).

Controls on formation of ore:

1. Trans-Challis fault system: Pre-mineralization 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-mineralization faults, the gouge served as an impermeable barrier, diverting mineralizing solutions into the permeable fractures (Ballard, 1924).
3. Depth of mineralization: The tendency for metal concentrations in ore bodies to be less at shallow depths and the epithermal character of the ore indicate a narrow vertical range of mineral deposition. 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 many 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.

RESOURCE ASSESSMENT

From the descriptive model above, we define 10 recognition criteria, of which 4 are diagnostic and 6 permissive.

Diagnostic criteria:

1. Evidence of precious-metal mineralization: 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. The most favorable are 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) are 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, we divided the quadrangle into 51 areas (pl. 3). The area boundaries were first tentatively established around localities showing 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. 94, for an explanation of the scoring process). The scores are tabulated in table 13.

Table 13. Scores for recognition criteria for precious-metal veins in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 3 for location of numbered areas]

	Diagnostic criteria					Permissive criteria							
Map area	Evidence of precious metals	Planar high-angle faulting	Tertiary hypabyssal intrusive rocks	Open-space filling	Total	Proximity to trans-Challis fault system	Widespread altered rocks	Localized altered rocks	Proximity to major mines	Proximity to pros-pects	Cu-Pb-Zn anomalies	Total	Resource potential
1	½	½	0	0	1	-1	0	0	-1	½	-1	-2½	Low
2	1	½	0	0	1½	-1	0	1	-1	½	-1	-1½	Low
3	½	0	0	0	½	-1	0	0	-1	½	-1	-2½	Low
4	½	½	0	0	1	-1	0	0	-1	-1	-1	-4	Low
5	1	1	½	0	2½	-1	1	1	-1	1	½	1½	Moderate
6	1	½	0	0	1½	-1	0	0	-1	½	½	-1	Low
7	1	0	½	0	1½	-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	½	-1	-1	-1	- ½	High
11	1	1	½	1	3½	1	1	1	1	½	½	5	High
12	½	½	0	½	1½	-1	1	0	-1	1	1	1	Low
13	½	0	0	0	½	-1	0	0	-1	0	1	-1	Low
14	½	1	1	0	2½	½	0	0	-1	0	-1	-1½	Low
15	½	½	1	½	2½	1	1	1	-1	-1	-1	0	Moderate
16	½	0	1	0	1½	½	0	0	-1	½	½	½	Low
17	1	0	½	0	1½	-1	0	0	-1	1	-1	-2	Low
18	1	½	1	0	2½	-1	0	0	-1	1	-1	-2	Low
19	1	½	1	0	2½	-1	½	0	-1	1	½	0	Moderate
20	1	½	0	0	1½	-1	1	½	-1	1	½	1	Low
21	½	½	1	0	2	-1	0	0	-1	-1	½	-2½	Low
22	1	0	1	0	2	-1	1	½	-1	-1	½	-1	Low
23	1	0	1	0	2	-1	1	½	-1	1	½	1	Low
24	1	0	1	0	2	-1	0	0	-1	1	-1	-2	Low
25	1	0	1	0	2	½	1	1	-1	1	1	3½	Moderate

Map area	Diagnostic criteria: Evidence of precious metals	Planar high-angle faulting	Tertiary hypabyssal intrusive rocks	Open-space filling	Total	Permissive criteria: Proximity to trans-Challis fault system	Widespread altered rocks	Localized altered rocks	Proximity to major mines	Proximity to prospects	Cu-Pb-Zn anomalies	Total	Resource potential
26	1	0	1	0	2	½	0	0	-1	1	-1	- ½	Low
27	1	0	1	0	2	½	0	0	-1	1	-1	- ½	Low
28	½	½	1	0	2	1	½	0	-1	½	-1	0	Low
29	1	1	0	0	2	-1	0	0	-1	-1	½	-2½	Low
30	1	½	0	0	1½	-1	1	½	-1	1	1	1½	Low
31	1	1	1	1	4	1	1	1	1	1	½	5½	High
32	½	1	1	0	2½	1	0	0	-1	-1	-1	-2	Low
33	1	1	0	0	2	1	1	0	-1	-1	½	½	Low
34	1	1	½	1	3½	-1	½	½	1	½	½	2	High
35	1	½	0	0	1½	-1	0	0	-1	-1	-1	-4	Low
36	1	0	½	0	1½	-1	0	0	-1	-1	½	-2½	Low
37	1	½	1	1	3½	1	1	1	1	1	-1	4	High
38	1	0	0	0	1	1	½	0	-1	1	-1	½	Low
39	½	½	1	0	2	½	0	0	-1	½	1	1	Low
40	½	1	½	0	2	-1	0	0	-1	-1	-1	-4	Low
41	½	½	0	0	1	-1	0	0	-1	-1	-1	-4	Low
42	½	1	1	½	3	-1	½	½	-1	½	-1	-1½	Moderate
43	½	0	0	0	½	-1	0	0	-1	-1	1	-2	Low
44	1	0	½	0	1½	-1	0	0	-1	-1	1	-2	Low
45	1	½	1	0	2½	½	½	½	-1	-1	1	½	Moderate
46	½	1	1	½	3	1	1	½	1	½	½	4½	High
47	1	½	1	½	3	1	1	½	1	½	1	5	High
48	½	½	1	0	2	1	0	0	-1	-1	½	- ½	Low
49	1	1	1	1	4	1	1	1	1	1	1	6	High
50	½	½	0	0	1	½	0	0	0	½	-1	0	Low
51	--	--	--	--	--	--	--	--	--	--	--	--	None

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 13, areas 9–11, 31, 34, 37, 46, 47, and 49 are ranked as having a high potential for the presence of additional precious-metal vein deposits. 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 described above, is present.

Areas 5, 15, 19, 25, 42, and 45 are ranked as having a moderate resource potential. 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, 16–18, 20–24, 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 being present. 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 around only 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 part outside the areas considered above, was not assessed for precious-metal vein deposits due to absence of diagnostic criteria.

Additional potential for gold and silver resources in disseminated deposits exists in the broad zones of altered rock 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 (Thorny 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 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 those 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 assessment. 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, having ore grades of a few hundredths of an ounce 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[7]

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. We believe that mixed base- and precious-metal veins are Cretaceous in age and 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. 2). 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 from others in the Grimes Pass and Summit Flat districts is listed in table 12.

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 veins that follow bedding at two different stratigraphic horizons of Proterozoic metasedimentary rocks. The Twin Peaks deposit is discussed under the section on stratabound cobalt-copper deposits (Johnson and Bennett, this volume, p. 175).

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, some veins being as thick as 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 14, 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). A drift 1,100 ft long (as of November 1986) on the Lower Rufus level of the Greyhound mine exposed three ore shoots in the Greyhound vein, each about 75 ft in strike length and about 8 ft in thickness (S. Hornbaker, oral commun., 1987). On the 7,200-ft-adit level, the Seafoam vein is 4–5 ft thick (unpublished U.S. Department of Defense Minerals

[7]Idaho Geological Survey.

Table 14. Production from mixed base- and precious-metal veins, 1904–1984, Challis 1°×2° quadrangle, Idaho.

[Unpublished U.S. Bureau of Mines data, Spokane, Wash.; —, no recorded production]

Mine name	Gold (oz)	Silver (oz)	Copper (lbs)	Lead (lbs)	Zinc (lbs)
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.

Exploration Administration 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 1 ft or so thick and tens of feet long.

Shape.—Ore shoots are lenticular, have a considerable range in thickness, and have sharp contacts with the wallrock.

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. Mill-head samples of higher grade ore from the largest stope in the Deadwood mine, taken 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, 2–3 oz silver per ton, and 3.5–4.5 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 14. 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.L. 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. Chalcopyrite was processed for its gold content 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, gold-bearing chalcopyrite. The ore shoots have well-defined walls, and the richest 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 is present in both the galena and the sphalerite. Ore shoots in the Greyhound vein consist of massive quartz, galena, and sphalerite. Silver content increases as lead content increases. Pyrite, galena, and sphalerite in quartz gangue form lenses along the Seafoam shear zone. Irregular lenses of quartz that include banded to massive occurrences of sulfide ore characterize many of the mixed veins.

Weathering products:

Outcrops of mixed veins exhibit various 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 30–40 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 would probably 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 15) and higher radiogenic values of $^{208}Pb/^{204}Pb$, which suggested 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 suggested to Doe that the lead came from a mixture of Archean and younger crustal materials. If Doe and Stacey (1974) were 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 showing low radiogenic lead content.

RESOURCE ASSESSMENT

From the foregoing descriptive model we define 10 recognition criteria of which 4 are diagnostic and 6 are permissive:

Diagnostic criteria:

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 criteria:

1. Presence of or proximity to leucocratic granite.
2. Absence of evidence indicating genetic association to Tertiary hypabyssal or plutonic rocks.
3. Presence of wall rock alteration.
4. Metal content anomalous 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. The resulting

Table 15. Lead-isotope data, mixed base- and precious-metal veins, Challis 1°×2° quadrangle, Idaho.

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

Sample No.	Material	Mine name	Atomic ratios		
			$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
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 16. Scores for recognition criteria for mixed base- and precious-metal veins in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 4 for location of numbered areas]

Map area	Diagnostic criteria				Total	Permissive criteria									Total	Resource potential
	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		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				Proximity to productive mines	Proximity to known mixed metal vein prospects		
									Cu	Pb	Zn	Ag				
1	-1	1	1	1	2	-1	1	0	½	- ½	- ½	½	-1	-1	-2	Low
2	1	1	1	1	4	-1	0	1	½	½	½	½	1	1	4	High
3	1	-1	1	-1	0	-1	0	0	½	0	0	0	-1	-1	-2½	Low
4	1	½	1	1	3½	1	-1	0	½	½	0	½	1	1	3	Moderate
5	1	-1	1	-1	0	1	-1	0	½	½	½	½	-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	½	½	½	½	-1	-1	-3	Low
8	1	1	1	-1	2	-1	-1	0	½	0	0	0	-1	-1	-3½	Low
9	1	-1	1	0	1	-1	-1	-1	½	½	½	½	-1	1	-1	Low
10	1	-1	1	1	2	1	-1	1	½	½	½	½	1	1	5	Moderate
11	1	1	1	1	4	1	-1	1	½	½	½	½	1	1	5	High
12	1	1	-1	-1	0	-1	-1	1	½	½	½	½	1	-1	1	Low
13	1	1	1	1	4	-1	1	1	½	½	½	½	1	1	5	High
14	1	½	1	1	3½	-1	-1	0	½	½	½	½	-1	-1	-2	Moderate
15	1	1	1	-1	2	-1	-1	0	0	½	0	½	1	-1	-1	Low
16	1	-1	1	-1	0	1	0	0	½	½	½	½	-1	-1	1	Low
17	1	1	1	-1	2	-1	-1	1	½	½	½	½	1	1	3	Moderate
18	1	1	1	-1	2	-1	-1	-1	½	½	½	0	-1	-1	-3½	Low
19	1	1	1	-1	2	-1	-1	1	½	½	½	½	1	-1	1	Moderate
20	-1	1	1	-1	0	1	-1	0	½	½	½	½	-1	-1	0	Low
21	1	-1	1	1	2	1	-1	-1	½	½	0	0	-1	-1	-2	Low
22	1	1	0	1	3	-1	-1	0	½	½	½	½	1	1	2	Moderate
23	1	-1	-1	-1	-2	-1	-1	0	0	½	½	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	½	½	½	½	-1	-1	-2	Low
26	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	None

scores are shown in table 16. From these semiquantitative scores, we ranked areas 2, 11, and 13 as having high potential for the presence of undiscovered vein deposits of mixed base and precious metals, areas 4, 10, 14, 17, 19, and 22 as having a moderate potential, and areas 1, 3, 5–9, 12, 15, 16, 18, 20, 21, and 23–25 as having a low potential for those types of deposits.

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 significant size or tonnage. 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 having moderate potential are considered less likely to contain these deposits; deposits are even less likely in areas having low potential. Areas that contain no mapped Idaho batholith have no potential for deposits of this type.

LEAD-SILVER-ZINC-ANTIMONY-TIN VEINS

By Wayne E. Hall

Lead-silver-zinc-antimony-tin vein deposits were mined extensively for their high silver content 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 are present in some deposits and could be significant byproducts. The deposits are predominantly small, discontinuous veins, lenses, and pods of ore in flat to steeply 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 about 3.5 mi. Some of the veins 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 (fig. 5) 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 (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, lead-silver ore bodies near the surface that were mined between 1879 and 1901. Fragmentary records indicate that of this, about $10 million worth of ore was mined from lead-silver vein deposits in the black shale belt within the Challis quadrangle. There was little exploration in 1980–84, and no major deposit was being mined.

Table 17 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 within the Bayhorse mining district. 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, which is low in silver. Galena and jamesonite from the other deposits have high silver content, 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 content, which does not correlate with high copper and antimony content.

The mineralogy of some of the vein deposits was determined by 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 the 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 18.

We evaluated the potential of the lead-silver-zinc-antimony-tin vein deposits as a possible tin resource. Tschanz and Kiilsgaard (1986) first recognized the area of anomalous concentration of 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 belt 29 mi long and 3–4 mi wide, extending from Boulder Basin in the Hailey 1°×2° quadrangle northward to the Livingston mine in the Boulder Mountains.

The high tin values shown by Tschanz and Kiilsgaard (1986, table 7, p. 126) indicated that significant resources of tin might occur in veins that cut the carbonaceous sedimentary rocks. We attempted to verify the tin content of the veins by re-analysis and resampling. 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 Kiilsgaard, 1986, table 7, p. 126) and resubmitted the samples for analysis. The re-analyzed 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 resampled the vein deposits that contain significant concentrations of tin. The analyses that were obtained (tables 17 and 19) are about one-third the values given by Tschanz and Kiilsgaard (1986, table 7, p. 126).

We believe several factors account for the differences between the two sets of data. Most important are use of different methods of analysis and possibly different sampling techniques. Our sampling method involved collection of approximately 3 lb of mineralized material from dumps and outcrops. The entire sample was pulverized and split for chemical analysis. Samples provided by Tschanz and Kiilsgaard were analyzed by semiquantitative spectrographic

Table 17. 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, Challis 1°×2° quadrangle, Idaho.

[All values in parts per million. Analyses are semiquantitative spectrographic determinations made in the U.S. Geological Survey Emission Spectrography Laboratory in Menlo Park, Calif.; project leader, R. Mays. N, not detectable; --, no data; <, less than; do, ditto]

Sample No.	Mine	Mineral	Ag[1]	As	Bi	Cd	Cu	Pb	Sb	Se	Sn	Te	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	Callda	. . 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	--	--	--	Do.

[1]To convert silver to ounces, divide parts per million 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, the listed mineral being predominant.

Table 18. Mineralogy of six lead-silver-zinc-antimony-tin veins in the central Idaho black shale terrane.

[Minerals identified by Robert Felder (microscopy and X-ray diffraction) and Robert Oscarson (scanning electron microscope). M, major (10 percent or more); C, common (3–9 percent); Mn, minor (1–2 percent); Tr, trace; -- not observed]

Mineral	Mine					
	Boulder Basin[1]	Crater Lake[2]	Coffee Pot[3]	Living-ston[2]	Stone-boat[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°×2° quadrangle at 43°50′ N., 114°31′ W.
[2]See plate 5.
[3]Located on the Hailey 1°×2° quadrangle at 43°54′ N., 114°38′ W.
[4]Located on the Hailey 1°×2° quadrangle at 43°55′ N., 114°38′ W.

techniques. Highest values result from quantitative X-ray fluorescence analysis of selected high-grade samples; analyses for this study were done by atomic-absorption analysis of both partially and completely digested samples. Because we were attempting to verify the presence of a significant resource, extra care was taken in both sampling and analysis. Therefore we are confident that these new data accurately represent the localities sampled.

Our analyses show that deposits that contain anomalous concentrations of tin are in the Salmon River assemblage 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 18. The tin is present predominantly as zincian stannite, but a little is present as cassiterite. The higher tin concentrations are present where the ores contain high silver and antimony concentrations and, in the Boulder Basin (43°50′ N., 114°31′ W.), high gold concentrations. Because the veins are narrow, the ore concentrated in rather small shoots and, the metallurgy being complicated, these deposits could not be considered a significant tin resource. However, they contain very high silver concentrations, and possibly tin could be recovered as a byproduct of the lead-zinc-silver ore.

DESCRIPTIVE MODEL

Ore body:

Size.—Pods contain a few tens of tons, and veins have a strike length of as much as 900 ft, pitch length of 1,500 ft, and thickness of 3–15 ft.

Shape.—Small lenses or pods to linear veins having a considerable range in thickness. Contacts with country rock are sharp.

Tonnage and grade.—A few hundred to several hundred thousand tons. Grade ranges from small lenses containing several hundred ounces silver per ton and 50 percent lead, to ore bodies of moderate size that range from 5 to 45 oz silver, 5 to 20 percent lead, 5 to 13 percent zinc, trace to 1 percent copper, 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, in approximate order of decreasing importance are silver, lead, zinc, gold, copper, antimony, tin, cadmium, arsenic.

Character of ore:

Mostly massive, fine- to coarse-grained sulfides, but it 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 rich in lead and silver or in lead, zinc, and silver and contain little pyrite or pyrrhotite gangue crop out inconspicuously. Coarse-grained galena may have an outer rind of brown, cellular iron oxide and a shiny, unaltered interior. In some places both sphalerite and galena form inconspicuous, fragile gossans that consist of limonite, cerussite, secondary yellow, powdery antimony oxides (bindheimite, for example) and quartz and calcite. Veins containing abundant pyrite, pyrrhotite, and arsenopyrite crop out as dark-brown or reddish-brown gossan. 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, which was a residual enrichment.

Lithology of host rock:

Black siliceous 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:

Zinc, lead, antimony, arsenic, silver, copper, organic carbon; siderite, jasperoid, quartz, calcite, and secondary zinc, lead, and antimony 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 body.
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 contributed greatly to 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. Location in a black-shale terrane.
2. Locally anomalous concentrations of lead and zinc.
3. Location 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 silver, antimony, tin.
6. Highly carbonaceous beds in the black shale terrane.
7. Presence of vein siderite or quartz.
8. Presence of Salmon River assemblage (Pzsr on Fisher and others, 1992, in pocket) or Ramshorn Slate (Or in Fisher and others, 1992, in pocket).
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. Each of the areas was then scored according to its diagnostic and permissive criteria (table 20). Areas 1, 6, and 10 were ranked as having high potential for the presence of undiscovered lead-silver-zinc-antimony-tin vein deposits, areas 2, 3, 5, 7–9, 12, and 14 as having moderate potential, and areas 4, 11, 13, and 15 as having a low potential for these types of deposits.

Areas 1, 6, and 10 each contain deposits that have been productive or have been extensively explored because of outcrops of mineralized rock. Each deposit is targeted

Table 19. 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.A. Roemer, analysts. N, not detected; <, less than; do, ditto; quad, quadrangle; Gl., gulch; Cr., creek]

Sample No.	Mine	Cu	Pb	Zn	Ag	As	Au	Bi	Cd	Mo	Sb	Sn[1]	Sn[2]	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[3]	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.

Sample No.	Mine	Cu	Pb	Zn	Ag	As	Au	Bi	Cd	Mo	Sb	Sn[1]	Sn[2]	Te	Location
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]Partial digestion.
[2]Complete digestion.
[3]Sample of concentrate from the Clayton Silver mill.

by geochemical halos of lead, zinc, barium, and silver. Each area is considered to have a high potential for additional undiscovered ore within the geochemically anomalous areas.

Within the areas of moderate potential, attention is directed to the anomalous concentrations of silver and zinc in the Grand Prize Formation next to the Idaho batholith in area 5. This is the largest area of anomalous concentrations of silver shown by stream-sediment samples in the Challis quadrangle, but no deposits are known to be present in the area. Area 3, west of the Bayhorse district, has moderate potential for deposits of this type because the volcanic cover is discontinuous and windows of Paleozoic rocks are present. Most of the areas that have been classified as having moderate potential are within the black shale terrane but more than 4 mi from a granitic pluton, or they are in black shale terrane within 4 mi of a granitic pluton but show only minor anomalous concentrations of metals in the regional stream-sediment sampling.

Areas of low potential are areas underlain by granite or volcanic terrane outside of 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 roof pendants. Area 13, east and northeast of the black shale terrane, also has a low potential because of the thick cover of Challis Volcanic Group.

Table 20. Scores for recognition criteria for lead-silver-zinc-antimony-tin veins in the Challis 1°x2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion. See plate 5 for location of numbered areas]

Map area	Diagnostic criteria				Permissive criteria										
	Black shale terrane	Anomalous Pb and Zn	<4 miles from granitic pluton	Total	Regional thrust fault	Gossan	Barite deposits	Exten-sional tectonics	Anom-alous Ag, Sn, Sb	Highly carbona-ceous host	Vein siderite or quartz	Pzsr or Or host	Produc-tive deposit in area	Total	Resource potential
1	1	1	1	3	1	1	0	0	1	1	1	1	1	7	High
2	1	½	-1	½	1	0	0	0	0	1	0	1	-1	2	Moderate
3	0	1	0	1	1	½	0	0	1	½	1	-1	1	4	Moderate
4	0	0	0	0	0	0	0	0	0	-1	0	-1	-1	-3	Low
5	½	½	½	1½	0	0	½	1	½	½	0	0	-1	1½	Moderate
6	1	1	1	3	1	½	0	0	½	1	1	1	1	6	High
7	1	1	-1	1	1	0	0	0	1	1	0	1	0	4	Moderate
8	1	½	½	2	0	½	0	0	½	1	½	-1	½	2	Moderate
9	1	0	1	2	1	0	0	0	0	1	0	1	-1	2	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	½	0	0	0	0	½	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	½	0	0	0	0	1	0	1	-1	1½	Moderate
15	-1	-1	0	-2	-1	0	0	0	½	-1	0	-1	-1	-3½	Low

FLUORSPAR VEINS

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

Fluorite is a common gangue mineral in many base- and precious-metal veins in the Challis quadrangle. However, fluorspar 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, some stringers and lenses cutting obliquely across the zones (Anderson, 1943a; Cox, 1954). The deposits are within a northeast-trending belt 0.5 mi wide and 2 mi 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 as much as 10 ft 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). The host rock is the 47- to 48-m.y.-old tuff 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-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-striking 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 ranges from trace to 1.5 oz per ton (Van Noy and others, 1986, p. 439). Chip samples, ranging in length from 1 to 3 ft, 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. A grab sample of dump material from the Gold Chance claims on the east side of Big Casino Creek yielded 45 percent CaF_2 (Van Noy and others, 1986, p. 443). 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-1940's (Choate, 1962). Drilling in the Casino Creek area indicates a potential of 200,000 tons of fluorspar ore with a grade of 20–30 percent CaF_2 (Tschanz and Kiilsgaard, 1986, p. 122).

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 20–700 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:

Size.—Veins contain ore shoots 1–20 ft wide and as much as 900 ft long. Veins may be present in zones as much as 0.5 mi wide and 2 mi long.

Shape.—Lenses, pods, planar veins, and aggregates of veinlets that crosscut one another in some places but that are mostly parallel. There are some breccia deposits. Veins are mostly open-space fillings with minor replacement.

Tonnage and grade.—Grades are variable, ranging from a few percent to more than 85 percent CaF_2. Deposits range from a few tons to lodes containing thousands of tons. Grades within some individual lodes are highly variable.

Mineralogy:

Ore minerals.—Fluorspar; gold and silver in some deposits in the Stanley district.

Gangue minerals.—Barite, chalcedony, quartz, calcite, minor pyrite, and stibnite.

Major commodities:

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 replacement of wall rocks. Ores include fine, grainy aggregates, 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 rock in Meyers Cove is tuff of Camas Creek–Black Mountain (Fisher and others, 1992, in pocket), a thick section of welded ash-flow tuff 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 porphyritic granodiorite 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 fluorspar vein deposits are enriched in molybdenum, gold, and silver. Some panned concentrates of these sediments contain tin.

Controls on formation of ore:

Productive fluorspar deposits are found associated with or along northeast-striking fault and fracture systems that 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 fluorspar vein deposits are within the trans-Challis fault system, so areas within this 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 concentrates 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 21). Two areas (9, 14) were ranked as having high potential; four areas (6, 8, 12, 13) as having moderate potential; and the remaining twelve as having low potential.

In area 9, the Seaforth Mining Company estimates that 1 million tons of fluorspar ore having 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 in 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 exists in the Casino Creek deposits (Van Noy and others, 1986, p. 440). 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 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. 163).

In areas ranked as having moderate potential, there is only a small probability that fluorspar vein deposits of the size described here exist. 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, fluorspar vein deposits.

Table 21. Scores for recognition criteria for fluorspar veins in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion. See plate 6 for location of numbered areas]

Map area	Diagnostic criteria				Permissive criteria					
	Planar high-angle faults	Evidence of fluorspar mineralization	Tertiary hypabyssal intrusions	Total	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	½	0	0	½	-1	½	½	-1	-1	Low
2	1	0	0	1	-1	½	½	-1	-1	Low
3	½	0	0	½	-1	½	½	-1	-1	Low
4	1	0	0	1	-1	0	0	-1	-2	Low
5	1	0	½	1½	-1	½	½	-1	-1	Low
6	1	½	1	2½	-1	0	0	-1	-2	Moderate
7	½	0	1	1½	½	0	½	½	1½	Low
8	½	1	½	2	-1	0	0	-1	-2	Moderate
9	1	1	1	3	1	½	½	1	3	High
10	1	0	0	1	½	½	½	½	2	Low
11	1	0	½	1½	½	1	1	½	3	Low
12	1	1	0	2	-1	1	½	-1	- ½	Moderate
13	1	½	1	2½	1	½	½	1	3	Moderate
14	1	1	1	3	1	½	½	1	3	High
15	½	0	½	1	½	1	½	½	2½	Low
16	1	0	1	2	1	½	1	½	3	Low
17	½	0	½	1	½	½	½	-1	½	Low
18	½	0	0	½	½	½	1	-1	1	Low

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) totaled 789 tons of ore at 0.18 percent U_3O_8, yielding 2,840 lb of U_3O_8 (Wopat and others, 1980, p. 25). Choate (1962) reported that about 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 was 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 estimated 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 lb U_3O_8. Wopat and others (1980) attributed the anomalous radioactivity to the presence of thorium and reported 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 deposit type different from 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 interested in veins containing radioactive minerals. The following description and assessment are based on the deposits at Basin Creek.

DESCRIPTIVE MODEL

Ore body:

Size.—As much as several hundred feet long and as wide.

Shape.—Lenticular, irregular, tabular.

Tonnage and grade.—As much as tens of thousands of tons of ore at an average grade of several tenths of a 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 1 mm to 1 in. (Choate, 1962, p. 30).

Lithology of host rocks:

These veins are found in medium- to coarse-grained biotite granodiorite and porphyritic granodiorite of the Cretaceous Idaho batholith. Dikes of Tertiary age, ranging in composition from rhyolite to dacite, intrude the biotite granodiorite 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 rarely disseminated in the host rock.

Geochemical and Mineralogical Indicators:

Mineralized rocks are enriched in Ag, As, Mo, Pb, Sb, Y, and Zn relative to unmineralized batholith rocks; mineral indicators are quartz, chalcedony, and 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 granodiorite.
2. Presence of aplitic or pegmatitic dikes.
3. Presence of steeply dipping to vertical fractures or joints.
4. Evidence of uranium mineralization, such as presence of known mines and prospects or 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 concentrations of Ag, As, Mo, Pb, Sb, Y, and Zn.

On the basis of these criteria, we divided the quadrangle into 20 areas (pl. 7), scored each area (table 22), and then ranked it for its potential for undiscovered deposits of the type described above. Areas 15 and 19 were ranked as having high potential for the presence of undiscovered uranium veins, areas 6, 8, 10, and 18 as having a moderate potential, and areas 1–5, 7, 9, 11–14, 16, 17, and 20 as having a low potential for these types of deposits.

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 ranked as having low potential have little likelihood of containing undiscovered uranium veins.

Table 22. Scores for recognition criteria for uranium veins in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion. See plate 7 for location of numbered areas]

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	½	½	-1	-1	½	½	-1	0	Low
2	1	½	½	-1	1	½	½	-1	0	Low
3	½	½	½	-1	½	½	½	1	2	Low
4	-1	0	1	-1	-1	0	0	1	1	Low
5	-1	½	½	1	1	0	0	-1	-1	Low
6	1	½	0	½	2	0	0	½	½	Moderate
7	-1	½	½	-1	-1	0	0	1	1	Low
8	1	0	1	½	2½	0	0	-1	-1	Moderate
9	-1	0	0	½	- ½	0	0	½	½	Low
10	1	0	½	1	2½	½	0	-1	- ½	Moderate
11	-1	½	1	-1	- ½	0	0	1	1	Low
12	-1	½	1	-1	- ½	1	½	1	2½	Low
13	-1	0	1	-1	-1	1	½	1	2½	Low
14	1	0	½	-1	½	0	0	½	½	Low
15	1	1	1	1	4	1	1	1	3	High
16	1	0	0	-1	0	½	0	1	1½	Low
17	1	½	½	-1	1	½	½	1	2	Low
18	1	½	1	-1	1½	½	½	1	2	Moderate
19	1	½	½	1	3	0	0	-1	-1	High
20	-1	½	½	-1	-1	½	½	½	1½	Low

TUNGSTEN VEIN AND REPLACEMENT DEPOSITS

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

The tungsten vein and replacement mines and prospects are 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 Payette, South Fork Salmon, Boise Ridge, and Deadwood faults (fig. 2) 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, 1992, in pocket). These faults have a large strike-slip component, and some are upthrown on the west as much as 1,500 ft (Kiilsgaard and Lewis, 1985).

Examples of tungsten vein and replacement deposits and occurrences are at the Yellow Pine, West End, Meadow Creek, Quartz Creek (Skipper), Golden Gate, and Mary 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 gold and 30,000 oz silver 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 lb 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 (B.F. Leonard, oral commun., 1985). The Mary Blue mine produced 7,900 oz of gold (Howard Nickelson, written commun., 1953).

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

DESCRIPTIVE MODEL

Ore body:

Size.—Tens to hundreds of feet wide, hundreds to thousands of feet long, and tens to hundreds of feet thick.

Shape.—Irregular, controlled by faults.

Tonnage and grade.—Ranges from several thousand to several million 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, silver, chalcopyrite, galena, sphalerite, tetrahedrite.

Gangue minerals.—Arsenopyrite, pyrite, quartz, calcite, feldspar, chlorite, epidote, fluorite, cinnabar.

Commodities:

Tungsten, antimony, gold, silver, copper.

Alteration:

The rock is strongly brecciated, silicified, and sericitized. Several stages of fracturing and brecciation are shown by infillings of quartz and scheelite. Clay minerals resulted from the intense brecciation and alteration of feldspars. The altered granodiorite is 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, containing chalcedonic quartz and euhedral quartz crystals lining cavities. Manganese oxides are common and scorodite is present in some places. At the Golden Gate and Quartz Creek mines the miners followed the manganese oxides to find higher grade tungsten ore.

Character of ore:

1. Fissure-filling quartz veins and veinlets form a stockwork.
2. Movement along the faults is postdated mineralization.
3. Scheelite was localized by carbonate-rich inclusions in the Idaho batholith. Remobilized calcite was preferentially replaced by scheelite instead of calcite in the metasedimentary carbonate inclusions.

Lithology of 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 fault zones, which may be several miles long and commonly several hundreds of feet wide.
2. Mineralized rock occurs where regional shear zones striking north to N. 20° E. intersect local faults striking N. 30°–60° E.

Geochemical and Mineral Indicators:

Antimony, arsenic, gold, and silver in both rocks and stream sediments; 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. Presence of secondary silica enrichment.
2. Presence of north-striking faults.
3. Presence of rocks of Cretaceous Idaho batholith.

4. Presence of tungsten minerals or geochemical anomalies of tungsten.

Permissive criteria:

1. Proximity to branching faults striking N. 30°–60° E.
2. Presence of carbonate metasedimentary inclusions.
3. Evidence for sericitic alteration.
4. Presence of argillically altered rocks.
5. Presence of manganese oxides.
6. Known occurrences or chemical anomalies of antimony.
7. Known occurrences or chemical anomalies of arsenic.

On the basis of the above diagnostic and permissive criteria the quadrangle was divided into nine areas (pl. 8). The scores for each area are listed in table 23. Areas 1 and 3 were ranked as having high potential for the presence of undiscovered tungsten vein and replacement deposits, areas 4, 8, and 9 as having a moderate potential, and areas 2 and 5–7 as having low potential for these types of deposits.

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 tungsten vein and replacement deposits. We believe that areas 1 and 3 contain at least one additional ore deposit comparable to the descriptive model. 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.

Table 23. Scores for recognition criteria for tungsten vein and replacement deposits in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion. See plate 8 for location of numbered areas]

	Diagnostic criteria					Permissive criteria								
Map area	Secondary silica enrichment	North-striking faults	Cretaceous plutonic rock	Tungsten minerals or geochemical anomalies	Total	Branching easterly faults	Carbonate inclusions	Sericitic altera-tion	Argillic altera-tion	Manganese oxides	Antimony minerals or geochemical anomalies	Arsenic minerals or geochemical anomalies	Total	Resource potential
1	1	1	1	1	4	½	1	1	1	1	1	1	6½	High
2	0	½	1	½	2	½	½	0	0	0	-1	½	½	Low
3	1	1	1	½	3½	½	½	1	½	½	½	½	4	High
4	½	½	1	1	3	0	½	½	0	0	½	½	2	Moderate
5	½	-1	1	1	1½	½	½	1	1	½	-1	½	3	Low
6	1	-1	-1	½	- ½	½	-1	0	1	0	0	½	1	Low
7	½	1	-1	1	1½	½	½	-1	-1	0	½	½	0	Low
8	½	½	1	½	2½	½	½	½	½	0	½	½	3	Moderate
9	½	½	½	½	2	½	½	0	1	0	0	½	2½	Moderate

MANGANESE VEINS

By Thor H. Kiilsgaard

The largest area of manganese-bearing rock 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. 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 manganese, 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° E., dips 70° NW., and may be traced for several hundred feet along strike. Unevenly spaced along the vein are lenses of black manganese-coated vein material as much as 20 ft wide and 40 ft long. A chip sample taken across a 10-ft segment of the largest lens contained 1.8 percent manganese, and a sample taken nearby 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 granite, and probably is an oxidation product from rhodochrosite. Rhodochrosite, in veinlets ranging from 1 to 4 in. thick, crops out upstream from the large vein, and these or similar veinlets could have supplied the manganese oxide that has stained the surface exposures.

Rhodochrosite in veinlets ranging from 0.25 to 1 in. thick also is 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 a significant 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 in places 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 minor amounts of manganese.

Manganese occurrences of these types contain such small amounts of manganese that they cannot be considered as resources. For this reason, we did not develop recognition criteria or attempt any further assessment of this deposit type.

SEMIPRECIOUS-OPAL VEINS

By Frederick S. Fisher

Semiprecious 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 50–100 ft thick below an obsidian-bearing rhyolite (Cater and others, 1973, p. 371). Other opal occurrences have been reported near the confluence of Panther Creek and Opal Creek (44°54′N., 114°19′ W.) and on a tributary of the South Fork 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.

STOCKWORK DEPOSITS

CRETACEOUS MOLYBDENUM STOCKWORKS

By Wayne E. Hall

Molybdenum-bearing stockworks in or near Cretaceous biotite granodiorite have been recognized in several localities in the Challis quadrangle (pl. 9). The largest of these, and the only one that has been developed, is at the Thompson Creek mine. Other deposits occur at Little Boulder Creek, Boulder Chain Lakes, Big Boulder Basin, and at the head of Cabin Creek (Mt. Jordan 7½-minute quadrangle). Molybdenum also occurs in Tertiary stockworks; these are discussed by Kiilsgaard and Bennett (this volume, p. 131).

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 southeastern California to southeastern 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 related to subduction zones. Molybdenum stockwork deposits associated with Cretaceous granitoid stocks in the Challis quadrangle occur within this magmatic arc.

The Thompson Creek deposit 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 from northwest to southeast 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), from which is taken the following description of the mineralization of the Thompson Creek deposit (p. 352):

> 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 frequency ranges considerably within the ore zone. Sulfide minerals other than molybdenite are scarce.

Mineralization occurred at Thompson Creek in Late Cretaceous time. Two samples of hydrothermal 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)[8]. The silver apparently is in the carbonaceous matter, but the form is not known.

A second large molybdenum stockwork deposit, at Little Boulder Creek in the White Cloud Peaks, lies within a down-dropped belt of contact-metamorphosed, fine-grained, limy sandstone (tactite) of unit 6 of the Wood River Formation on the east side of the Cretaceous White Cloud stock. The deposit was 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 slope 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. that brought the tactite on the northwest against Challis Volcanic Group on the southeast. The White Cloud stock is 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 northernmost, 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 stock, 1,395 ft long and 820 ft wide, that is elongate north-south and is east of the White Cloud stock. This ore body is spatially and probably genetically related to the Little Boulder Creek stock. The Little Boulder Creek stock ranges in texture within the same outcrop from fine- to medium-grained equigranular biotite-amphibole granodiorite to coarsely porphyritic leucocratic granite. The stock has been silicified and has undergone intense potassic alteration. Coarse twinned plagioclase and potassium feldspar in the original granodiorite has been replaced by fine-grained, untwinned potassium feldspar that has been altered, in part, to sericite and clay minerals.

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[8]Analyzed by emission spectroscopy by J.J. Consul under the direction of Robert Mays, U.S. Geological Survey.

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, the ore body is covered by talus and glacial debris and on the south by alluvium and Challis Volcanic Group. The host rock is a medium- to dark-green, medium-grained, dense pyroxene tactite containing diopside, quartz, feldspar, amphibole, andradite garnet, and epidote adjacent to the stock. The grade of metamorphism within the ore body decreases to the east away from the stock, from tactite to lighter green calc-silicate rock containing 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 drilled a number of holes. According to Kirkemo and others (1965), the U.S. Bureau of Mines sampling indicated the north ore body contains a large 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 for WO_3 13 samples from the north zone and 6 from the south zone (Van Noy and others, 1986, p. 245). 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 showed 77.3 ppm rhenium (Jean Mark Luck, written commun., 1983).

The southernmost ore body is evident as 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 ore body, but neither the amount of outcrop nor exploration has been sufficient to delineate grade and tonnage.

Other areas of Cretaceous molybdenum stockworks in the Challis quadrangle are known 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 that has been prospected is in the Mt. Jordan 7½-minute 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 contains abundant secondary biotite and muscovite.

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

DESCRIPTIVE MODEL

Ore body:

Size.—Several thousand feet long; several hundred feet wide; several hundred feet thick.

Shape.—Elongate tabular bodies whose tops are commonly arched or domed.

Tonnage and grade.—From 25 to 600 million tons. Grade ranges from 0.055 to 0.16 percent molybdenum.

Mineralogy:

Ore minerals.—Molybdenite with or without scheelite, chalcopyrite, galena, and silver minerals.

Gangue minerals.— Quartz, pyrite, muscovite, and biotite.

Major commodities:

Listed in order of decreasing 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 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, argillic, and probably propylitic. Intense silicification is 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 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 flanks 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 low-fluorine, I-type granitic plutons or multiple plutons, having a high Sr/Rb.
2. Zones of potassic alteration grading outward and (or) upward to zones of phyllic alteration.
3. Local anomalous molybdenum concentrations.
4. Presence of quartz stockwork.

Permissive criteria:

1. Evidence of argillic alteration and (or) propylitic alteration and disseminated pyrite.
2. Anomalous concentrations of one or more of the following: tungsten, silver, copper, gold, lead.
3. Presence of mineralized skarn adjacent to granitic plutons.
4. Light-colored limonitic gossan containing yellow ferrimolybdite.
5. Location on 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 having low potential to areas of high potential for Cretaceous molybdenum stockwork deposits. Each area was evaluated for the diagnostic and permissive criteria and the results are given in table 24.

Areas 5 and 8 are classified as having high potential for Cretaceous molybdenum stockwork. Each has a large stockwork deposit. The Thompson Creek deposit, which is being mined by the Cyprus Mining Company, has 200 million tons of 0.18 percent MoS_2 and a significant amount of byproduct silver. The Little Boulder Creek deposit in area 8 is a measured resource of more than 100 million tons of ore containing 0.15 percent MoS_2 and 0.02 percent tungsten in scheelite. Area 8 contains molybdenite in mineralized 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. Some stream-sediment samples from areas 9, 11, 12, and 14 have anomalous molybdenum concentrations, and these areas contain granitic rocks that range in composition from granodiorite to leucogranite. Known molybdenite occurrences, however, appear to be subeconomic. These include the molybdenite in stockwork at the head of Cabin Creek, in the Mt. Jordan 7½-minute quadrangle and the mineralized rock at the Virginia-Beth prospect. Anomalous molybdenum concentrations were found on the west side of area 12, in an area underlain by Cretaceous biotite granodiorite and leucogranite. There are no known molybdenite prospects in the area.

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 showed no anomalous molybdenum concentrations in stream-sediment samples.

Fluorine-deficient molybdenum deposits in the former 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 in the Idaho deposits, their paragenesis is similar to that of the Soviet Union deposits. This similarity suggests that some potential for gold exists wherever there is potential for fluorine-deficient molybdenum deposits in the Challis quadrangle.

Table 24. Scores for recognition criteria for Cretaceous molybdenum stockworks in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion. See plate 9 for location of numbered areas]

Map area	Diagnostic criteria					Permissive criteria							
	Low-F granitic pluton having high Sr/Rb	Potassic-phyllic alteration	Anomalous Mo concen-trations	Quartz stockwork	Total	Argillic and (or) propyllic alteration	Anomalous concentrations of W, Ag, Cu, Au, Pb	Presence mineralized skarn	Gossan with yellow ferrimolyb-dite	Margin of magnetic high	Destruction of magnetite in altered granite	Total	Resource potential
1	-1	-1	½	0	-1½	-1	-1	0	0	-1	0	-3	Low
2	1	0	½	0	1½	½	1	0	0	1	0	2½	Moderate
3	0	-1	0	0	-1	0	½	0	0	1	0	1½	Low
4	0	-1	-1	0	-2	0	½	0	0	1	0	1½	Low
5	1	1	1	1	4	1	1	1	1	1	1	6	High
6	0	0	½	0	½	½	½	½	½	½	0	2½	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	½	1	1	1	0	0	3½	Moderate
10	-1	-1	0	-1	-3	-1	-1	0	-1	-1	0	-4	Low
11	1	0	1	½	2½	½	½	0	½	½	0	2	Moderate
12	1	0	1	0	2	0	0	0	-1	-1	0	-2	Moderate
13	½	0	-1	0	- ½	-1	0	-1	-1	0	0	-3	Low
14	1	0	0	0	1	0	½	½	0	½	0	1½	Moderate

TERTIARY MOLYBDENUM STOCKWORKS

By Thor H. Kiilsgaard and Earl H. Bennett

The largest Tertiary molybdenum deposits in the Challis quadrangle are vein stockworks and disseminated occurrences. These deposits are in or near hypabyssal rocks of Eocene age. The host rocks are intensely altered; the core of the altered area is commonly mineralized and silicified. Pyrite is the predominant 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, following zones of major fracturing and intrusion. They consist of a number of subparallel quartz veins that range from a few inches to a few feet in thickness, between which are myriad connecting quartz veinlets and stringers, all of which compose a vein-stockwork system. In some places molybdenite occurs as rosettes and aggregations along the quartz veinlets, and in other places it occurs as hair-thin veinlets of molybdenite or as disseminated flecks in the wall rock. The deposits contain minor amounts of copper and silver minerals. Some also contain minor quantities of gold. The CUMO and Little Falls deposits, in the southwest corner of the quadrangle, and the Red Mountain deposit, north of Yellow Pine, are typical of this deposit type. A mineralized area at the headwaters of Big and Little Silver Creeks, 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 secs. 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 sq mi.

The CUMO 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 the ages of at least one rhyolite dike and several small diabase dikes postdate mineralization. The core of the deposit is an intensely silicified zone, almost completely encircled by a pyritic envelope that is 600–700 ft wide on the eastern side of the deposit (Whitney, 1975).

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

The CUMO deposit is estimated to contain one billion tons of material having an average grade of 0.10 percent MoS_2 (D.J. Baker, oral commun., 1985). This grade is too low to be minable (as of 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 a significant molybdenum resource.

The Little Falls molybdenite deposit is along the South Fork 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 postdate mineralization. Fission-track dating of zircon from a rhyolite dike predating mineralization at the deposit gave an age of 29.3±1.7 m.y. (Paul Andriessen, written commun., 1982). The swarm of rhyolitic dikes can 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 most intensively pyritized rocks has colored the outcrop a reddish-brown and has created a strong molybdenum geochemical anomaly over part of the deposit (Rostad, 1967). Evidence of 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 more than 50 holes in the area, totaling 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 multimillion-ton deposit that 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 being in the Challis quadrangle. It is a stockwork of quartz veins and veinlets about 2,700 ft long and 2,000 ft wide, having 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 zone of argillic alteration. Although exploration to date has not disclosed significant amounts of molybdenite and soil samples are low in molybdenum, biogeochemical anomalies of gold and molybdenum have been found at the surface. Of particular interest is gold in samples taken from Douglas-fir (*Pseudotsuga menziesii*) and molybdenum from the leaves of beargrass (*Xerophyllum tenax*) (Erdman and others, 1985). The locality is 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, 1983a). Another mineralized area about 5 mi to the northwest, south of the sharp bend in Crooked River, also is anomalous in molybdenum and silver (Kiilsgaard and others, 1983b). 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 generally in such scanty amounts that it is of interest only from a mineralogical standpoint. 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. 136) have called attention to the possibility of molybdenum deposits beneath high-level rhyolite.

DESCRIPTIVE MODEL

Ore body:

Size.—As much as several thousand feet long; more than 1,000 ft wide.

Shape.—Somewhat oval in plan view, the long axis more or less parallel to the trend of the Eocene dike host rocks and to the most pronounced shear zones that predated mineralization and 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, and gold in trace amounts.

Mineralogy:

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

Commodities:

The major commodity is molybdenum, associated 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 is a distinctive color anomaly.

Alteration:

Host rocks of the deposits are intensively altered. A siliceous core surrounded by envelopes of pyritized, 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.

Controls on formation of ore:

The rhyolitic dikes are the primary structural controls, along with the faults of the trans-Challis fault system, which predate mineralization and commonly guided emplacement of both dikes and ore bodies.

RESOURCE ASSESSMENT

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

Diagnostic criteria:

1. Presence of Tertiary quartz stockworks.
2. Presence of Eocene dikes and stocks intrusive into Cretaceous granodiorite.
3. Presence of extensive hydrothermal alteration.
4. Presence of MoS_2 in stockworks or disseminations.

Permissive criteria:

1. Trace to moderate amounts of molybdenite throughout a broad, elongate zone.

2. Trace amounts of associated silver and copper.
3. Anomalous concentrations of molybdenum in stream sediments or in panned concentrates.
4. Anomalous concentrations of 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 these criteria, 12 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 25. From these scores we ranked areas 1, 11, and 12 as having high potential for the presence of undiscovered Tertiary molybdenum deposits, areas 2, 6, and 10 as having moderate potential, and areas 3–5 and 7–9 as having a low potential for these types of deposits.

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 U.S. Forest Service Primitive Area and more recently as a Wilderness. Area 6 contains the Cretaceous Thompson Creek molybdenum deposit (Hall, this volume, p. 127). 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 was not assessed for additional Tertiary molybdenum stockworks, due to the absence of diagnostic criteria.

Table 25. Scores for recognition criteria for Tertiary molybdenum stockworks in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 10 for location of numbered areas]

Map area	Diagnostic criteria					Permissive criteria							Resource potential
	Presence of Tertiary quartz stock-works	Presence of MoS_2 in stockworks or dissemi-nations	Eocene rhyo-lite dikes and stocks intrusive into Creta-ceous granodiorite	Extensive hydrothermal alteration	Total	Molybdenite occurs throughout a broad, elongate zone	Trace amounts of associated silver and copper	Anomalous molybdenum concentrations in stream sediments or panned concentrates	Anomalous molybdenum concentrations in soil samples	Area is within the trans-Challis fault system	Presence of siliceous ore with pyritic envelope	Total	
1	1	1	1	1	4	1	0	1	1	-1	1	3	High
2	½	½	½	0	1½	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	½	1	1	2½	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	½	1	0	1½	0	1	1	0	0	0	2	Low
10	0	½	0	1	1½	1	1	1	0	-1	0	2	Moderate
11	½	½	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	--	--	--	--	--	--	--	--	--	--	--	--	None

PRECIOUS-METAL DEPOSITS HOSTED BY HIGH-LEVEL RHYOLITES

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 intrusive bodies came to the surface—some breached it, others did not. The cooling history, hydrothermal fluid flow, and mineralization of rhyolites that vented are 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 rhyolite at Red Mountain yielded an age of 39.1±2.0 m.y. (Paul 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 Golden Sunbeam mine (Anderson, 1949) and the Parker Mountain (Ross, 1927, 1934b), Rabbit Foot (Ross, 1927), and Singheiser deposits (Ross, 1927). Production from these deposits has been relatively small (see table 26), and most of the recorded production has come from the largest, 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 quartz stockwork veins (less than 0.25 in. thick) and as disseminations in altered rhyolite. In 1980–1984 there were no active mines in deposits of this type, but exploration activity was extensive and a pilot production project had been completed at the Golden Sunbeam mine.

Table 26. Historic production from precious-metal deposits hosted by high-level rhyolites, Challis 1°×2° quadrangle, Idaho.

[Data from U.S. Bureau of Mines, Spokane, Wash.; production largely from high-grade veins]

Mine	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

DESCRIPTIVE MODEL

Ore body:

Size.—Tens to hundreds of feet wide; hundreds to thousands of feet long; tens to hundreds of feet thick.

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

Tonnage and grade.—Several thousand tons of ore varying from 0.02 to 1.0 oz gold; gold:silver 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 minerals.—Zircon, apatite, fluorite, amethystine quartz.

Commodities:

Gold and silver.

Character of ore:

Ore minerals concentrated in small, discontinuous 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.

Lithology of host rocks:

1. Host rocks are 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, host rocks are alkali rhyolites, having an average composition 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, stained by iron, and silicified. Hydrothermally altered zones contain clay pseudomorphs after feldspar and variable amounts of secondary and remobilized silica.

Geochemical and mineral indicators:

Stream sediments are commonly enriched in Ag, As, Au, Be, Mo, Se, and Zr (McDanal and others, 1984). Zircon, pyrite, amethystine quartz, fluorspar, and clays are characteristic.

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 that reflect the major structural trends. The fracture systems are commonly zones of shattering on which there has been little or no motion.
3. At the Golden Sunbeam mine, the highest gold concentrations 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: geochemical anomalies, mines or prospects, or placer deposits.
2. Presence of high-level rhyolites.
3. Proximity to bounding faults of major volcanotectonic features.
4. Location of deposits 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 hydrothermal 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 indicator minerals: zircon, pyrite, amethystine quartz, fluorite, or clays.
3. Extensive fracturing and brecciation of host rocks.
4. 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 27). 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. Qualitatively, we believe the available data indicate that areas 6 and 8 should have priority as target areas in prospecting for precious-metal deposits in high-level rhyolites. We believe the combination of recognition criteria is so compelling as to indicate a high probability that at least one additional 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 significant, but lower, probability that one additional 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 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. Eocene molybdenum-bearing stockworks in the Challis quadrangle are known to be associated with rhyolite dike swarms of the trans-Challis fault system (Kiilsgaard and Bennett, this volume, p. 131). It is likely that rhyolitic feeder dike systems underlie the high-level rhyolites described here. Anomalous concentrations of molybdenum in the high-level rhyolites suggest that stockwork molybdenum deposits may exist at depth.

Table 27. Scores for recognition criteria for precious-metal deposits hosted by high-level rhyolites, Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion. See plate 11 for location of numbered areas]

Map area	Diagnostic criteria						Permissive criteria					Resource potential
	Evidence of precious metals	High-level rhyolites	Major bounding faults	North part of trans-Challis fault system	Anomalous concentrations of silica	Total	As, Be, Mo, Se, or Zr anomalies	Anomalous concentrations of indicator minerals	Fracturing and brecciation	Argillic alteration	Total	
1	1	0	0	0	0	1	½	½	½	½	2	Low
2	1	½	1	-1	1	2½	1	1	1	1	4	Moderate
3	½	0	0	0	½	1	½	½	½	0	1½	Low
4	1	0	½	-1	½	1	0	½	1	½	2	Low
5	½	½	1	½	1	3½	½	½	½	½	2	Moderate
6	½	1	1	1	1	4½	1	1	1	1	4	High
7	½	½	½	½	1	3	½	½	½	½	2	Moderate
8	1	1	1	½	1	4½	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	½	0	0	½	Moderate
11	0	1	½	½	0	2	0	0	0	0	0	Low
12	0	1	½	½	0	2	0	0	0	0	0	Low
13	0	1	½	½	0	2	0	0	0	0	0	Low
14	0	1	1	-1	1	2	0	½	½	0	1	Low
15	0	1	-1	-1	0	-1	0	0	0	0	0	Low
16	0	1	½	-1	0	½	0	0	0	0	0	Low

DISSEMINATED DEPOSITS

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, 1992, in pocket). 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 1.5 mi 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, 1992, in pocket), the rocks are shown as Paleozoic(?) or Precambrian(?). Because graphite is derived from organic materials, its presence suggests that they more likely are of Paleozoic age. Relatively unmetamorphosed sedimentary rocks of Paleozoic age in the southeastern part of the quadrangle contain sufficient carbonaceous material to account for the graphite in the metamorphic rocks, whereas known Proterozoic metasedimentary rocks in the quadrangle do not.

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 U.S. Bureau of Mines (Van Noy and others, 1986) ranged from 1.99 percent to 3.00 percent organic carbon and averaged 2.54 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 (Van Noy and others, 1986, p. 383).

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. The graphitic material can be considered a resource, but the likelihood of its exploitation is small.

PEGMATITE DEPOSITS

MICA, FELDSPAR, COLUMBITE, AND RARE-MINERAL PEGMATITES

By Thor H. Kiilsgaard

Pegmatites are coarse-grained unevenly 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 commonly is quartz. Pegmatites have been intruded into the rocks that enclose them, and their shapes are determined by pre-existing structures in the host rock. The most common form is dikes that 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 pipelike structures, whereas others are tabular or irregularly 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, 1992, in pocket). The pegmatites cut biotite granodiorite of the Idaho batholith. The pegmatite at the Columbite prospect, in sec. 19, T. 8 N., R. 5 E., is an oval 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 1.25 in. in diameter, is concentrated in the plagioclase-quartz zone. Also present in the zone are columbite, samarskite, and monazite. A 309-lb crystal with an inner zone of columbite and an outer zone of samarskite 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. Still (1950) called attention to a zone 2–3 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 lb 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 C.C. Popoff (U.S. Bureau of Mines, unpub. data) 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 has 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 8–12 in. wide and exposed over a length of 15 ft. Mica books in the pegmatite are small and contain structural defects (reeves). Niobium, tantalum, and beryllium were not detected in samples of the pegmatite taken by L.E. Shaffer (U.S. Bureau of Mines, unpub. data, 1944).

The pegmatite at the Panther prospect is 1.75 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.

There are exposures of blue-green beryl (aquamarine) in the Sawtooth Range (Reid, 1963; Pattee and others, 1968; Kiilsgaard and others, 1970). The aquamarine occurs as erratic disseminations, commonly 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. Aquamarine is also concentrated 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 Sawtooth pegmatites known to 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 a 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-wide 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 because 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.

PEGMATITES CONTAINING PIEZOELECTRIC QUARTZ CRYSTALS

By Thor H. Kiilsgaard

Crystalline material that lacks a center of symmetry is piezoelectric, and quartz is among the most 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°48′ N., 116°00′ 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 lb. A clear quartz crystal from the deposit, examined by Hugh Waesche, U.S. Signal Corps Laboratories, was 10 in. in diameter and 14 in. long (oral 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°41′ N., 115°43′ 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, unpub. data, 1983), 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 no information on the grade or physical character of the deposit is available. There is no record of quartz having been shipped from the deposit.

Potential resources of piezoelectric quartz in the quadrangle are small because of the poor quality of crystals and small tonnage in identified prospects.

DEPOSITS IN MIAROLITIC CAVITIES

SEMIPRECIOUS GEMSTONES IN MIAROLITIC CAVITIES

By Earl H. Bennett[9]

Crystals of smoky quartz, microcline, topaz, and beryl (aquamarine) have been collected from Eocene pink granite 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 filled 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 commonly 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 granite is smoky quartz. Individual crystals reach a length of 16 in. and weigh as much as 100 lb. The crystals occur singly, in groups, and in some cases with microcline, topaz, and fluorite reminiscent of the Pike's Peak, Colo., specimens except that the Idaho microcline is typically tan or white, in contrast with 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 defects. 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. Some single crystals have been reported to be as much as 4 in. long. The crystals are commonly bluish 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 quadrangle.

Beryl crystals (var. aquamarine) occur in several of the granite plutons, most notably in the Sawtooth batholith. Pattee and others (1968) described most of the beryl occurrences in Idaho. Beryl is also reported to occur in the Crags and Twin Springs plutons. The aquamarine occurs in the Sawtooth batholith as subhedral to euhedral crystals in vugs, as veinlets along fractures or disseminations, and in crystals and massive aggregates in pegmatites. Rarely, gem-grade aquamarine occurs in cavities. These crystals could yield beautiful cut stones.

Surprisingly, few large crystals of any mineral have been reported to occur in the Casto pluton, the largest Tertiary granite body in the Challis quadrangle. The pluton does contain small miarolitic cavities filled with numerous small, euhedral microcline and smoky quartz crystals, but no large cavities or crystals have been reported.

Because the occurrences are scattered and access is difficult, the potential for large-scale production of gem stones from the Sawtooth batholith and other Tertiary granite in Idaho is low.

[9]Idaho Geological Survey.

SKARN DEPOSITS

POLYMETALLIC SKARN DEPOSITS

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

Polymetallic skarn deposits are defined here as sulfide and iron oxide deposits with silicate gangue (including amphiboles, pyroxenes, garnet, and wollastonite) that replaced argillite or dolomite. Favorable environments for such deposits are along the eastern margin of the Idaho batholith and its satellitic stocks and in carbonate beds in roof pendants within the Idaho batholith.

Examples of skarn deposits within the Challis quadrangle are at 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 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 Fourth of July Creek area. The Little Boulder Creek deposit in the White Cloud Peaks, although it contains mineralized skarn, is a molybdenum quartz stockwork deposit and is described elsewhere (Hall, this volume, p. 127).

Tungsten is the principal commodity that has been produced from the skarn deposits in the Challis quadrangle. The Springfield scheelite mine produced more than 5,940 units of WO_3 between 1953 and 1955 (Cater and others, 1973). Skarn containing scheelite and some molybdenite is stockpiled at the Tungsten Jim mine. Exploration at the Tungsten Jim mine, in the early 1950's, resulted in discovery of about 40,500 tons of tungsten ore that had an average grade of about 1.80 percent WO_3 (unpublished U.S. Department of Defense Minerals Exploration Administration report, 1960). 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 gold, 41.3 oz/ton silver, 34.1 percent lead, and 5.8 percent zinc (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:

Size.—Ranges from small pods to ore bodies several thousand feet long, tens to hundreds of feet wide, and hundreds of feet thick.

Shape.—Irregular to elongated pods.

Tonnage and grade.—From a few tons to several million tons. The grade ranges from 0.32 to 1.8 percent WO_3; 0.7 to 13 oz per ton silver; 0.5 to 11 percent lead; 2.3 to 15 percent zinc; 0.08 to 1.8 percent copper; 0.005 to 0.07 oz per ton gold.

Mineralogy:

Ore minerals.—Scheelite, sphalerite, molybdenite, chalcopyrite, galena.

Gangue minerals.—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 is fine to coarse grained.

Weathering products:

Weathers to a dark-brown or reddish-brown gossan that may contain secondary lead, zinc, and copper minerals. In places, residual enrichment of gold has formed a low-grade deposit that can be mined for gold.

Lithology of host 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, and clean limestone or micritic limestone interbedded with argillites in black shale host rocks.

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 includes diopside-hedenbergite, grossularite-andradite, wollastonite, idocrase, calcite, epidote, chlorite, and quartz.

Geochemical and mineral indicators:

W, Zn, Cu, Pb, Mo, As, Fe, ± Bi; characteristic skarn mineral assemblage.

Controlling structures:

Intrusive contact between a granitic pluton and carbonate host rock, and bedding, faults, and brecciated rock as local structural controls.

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 intrusive contact with sedimentary or metasedimentary rocks.
2. Presence of carbonate country rock.
3. Presence of skarn mineral assemblage.
4. Presence of geochemical anomalies (any or all): tungsten, zinc, copper, lead, molybdenum.

Permissive criteria:

1. Evidence of retrograde metamorphism.
2. Presence of scheelite or garnet in panned concentrates.
3. Presence of gossan.
4. Evidence of silicification.

From the above criteria we identified 13 areas that have a potential for polymetallic skarn deposits (pl. 12) and scored these areas as shown in table 28. From these scores we ranked areas 3, 8, 11, and 13 as having high potential for the presence of undiscovered polymetallic skarn deposits, areas 2 and 4 as having a moderate potential, and areas 1, 5–7, 9, 10, and 12 as having a low potential for these types of deposits.

Area 3 has extensive skarn zones in Washington Basin (44°02′ N., 114°41′ W.), Fourth of July Basin (44°03′ N., 114°39′ W.), and the Tungsten Jim mine area (pl. 12). Scheelite in skarn at the Little Boulder Creek deposit (see Hall, this volume, p. 127) 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 to be present there, 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.

Table 28. Scores for recognition criteria for polymetallic skarn deposits in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion. See plate 12 for location of numbered areas]

Map area	Diagnostic criteria: Intrusive contact with sedimentary or meta-sedimentary rocks	Diagnostic criteria: Intruded rocks include carbonate country rock	Diagnostic criteria: Skarn mineral assemblage	Diagnostic criteria: W±Zn±Cu ±Pb±Mo anomalies	Total	Permissive criteria: Retro-grade metamor-phism	Permissive criteria: Scheelite and (or) garnet in panned concentrates	Permissive criteria: Presence of gossan	Permissive criteria: Silici-fication	Total	Resource potential
1	-1	-1	-1	0	-3	-1	-1	0	-1	-3	Low
2	1	½	½	0	2	0	0	½	0	½	Moderate
3	1	1	1	1	4	1	1	½	1	3½	High
4	½	½	½	0	1½	0	0	½	½	1	Moderate
5	-1	-1	-1	0	-3	-1	-1	-1	-1	-4	Low
6	-1	0	0	0	-1	0	0	½	-1	- ½	Low
7	-1	½	-1	-1	-2½	-1	0	0	-1	-2	Low
8	1	1	½	0	2½	1	0	½	1	2½	High
9	-1	-1	-1	0	-3	0	0	0	0	0	Low
10	0	1	0	0	1	0	0	0	0	0	Low
11	½	1	0	1	2½	0	0	½	1	1½	High
12	-1	1	-1	0	-1	-1	-1	0	-1	-3	Low
13	1	1	½	0	2½	0	0	½	0	½	High

REPLACEMENT DEPOSITS

RARE-EARTH-MINERAL DEPOSITS IN SHEAR ZONES

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(?)-striking shear zones cut a calcareous metasedimentary unit of the Proterozoic 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 in combination with limonite, manganese oxides, clays, coarse euhedral quartz, chalcedony, pyrite, calcite, and traces of 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 metasedimentary rock that is not sheared.

The U.S. Bureau of Mines estimated that the Monumental Summit rare-earth-mineral occurrence contains 95,000 tons of material having 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 Cambrian and (or) Ordovician Bayhorse Dolomite, and the Ordovician Ella Dolomite and Saturday Mountain Formation. 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 in these roof pendants have been described (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 29 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 there was much production in the late 1800's and early 1900's from the Beardsley-Excelsior, Pacific, and Riverview mines on Bayhorse Creek and from the Red Bird and South Butte mines on Squaw Creek, 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 (see pl. 13 for mine locations). 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 properties having past production, 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 are of Late Cretaceous age.

Table 29. Production of base and precious metals from irregular replacement deposits in the Challis 1°×2° quadrangle, Idaho.

[Gold, silver production in ounces; copper, lead, zinc in tons; values based on average prices for main periods of production]

	Amount	Approximate value
Gold	2,612	$121,000
Silver	7,604,480	$11,000,000
Copper	784	$376,000
Lead	52,320	$10,250,000
Zinc	14,160	$3,059,000

DESCRIPTIVE MODEL

Ore body:

Size and shape.—Range from small pods a few feet or less in major dimension to more or less continuous, commonly irregularly shaped replacement bodies that may be several hundred to several thousand feet long, and range in thickness from a few feet to several hundred feet. Width may equal length but is commonly much less, resulting in generally elongated lenses or ovoid, pipelike 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 ft or more in diameter, distributed along a more or less continuous zone that is commonly controlled by bedding. Some of the ore bodies in the Red Bird mine were 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 size and shape 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 several hundred thousand 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 is 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 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 have been converted to masses of granular carbonates and sulfates of lead and zinc with silver chloride. The oxide ore bodies generally conform to the shape of the original replacement deposits; where they were mined deeply, as at the Red Bird mine, they grade into the sulfide ore zone.

Alteration and weathering:

The rocks are locally dolomitized in the 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:

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:

Geochemical anomalies of lead, zinc, silver, and copper are characteristic of soil samples from above the surface intercept of steep faults. Galena, sphalerite, and tetrahedrite are typical minerals 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 rocks.
2. Presence of steep, north-striking faults.
3. Evidence of base- and precious-metal mineralization. May be either geochemical anomalies, mines, or prospects.

Permissive criteria:

1. Presence of black shale terrane contiguous to carbonate terrane.
2. Location near overlying thrust faults.
3. Presence of intrusive rocks contiguous to carbonate terrane.
4. Presence of gossans.

Using the diagnostic criteria, we divided the quadrangle into 15 areas (pl. 13). Each area was scored (table 30) and ranked as to its potential—high, moderate, or low—for 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-metal 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 existence of at least one additional ore deposit (in either area 10, 11, or 12) comparable to the Red Bird mine in area 10, the Clayton silver mine in area 11, or the Excelsior or Riverview mine 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 lack some of the criteria and are rated as having moderate potential for the existence 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 low potential for the occurrence of any significant base- and precious-metal replacement deposits in these areas.

Table 30. Scores for recognition criteria for irregular replacement deposits of base and precious metals in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 13 for location of numbered areas]

Map area	Diagnostic criteria				Permissive criteria					Resource potential
	Carbonate rocks	Steep north-trending faults	Evidence of base- and precious-metal mineralization	Total	Contiguous black shale terrane	Overlying thrust faults	Contiguous intrusive rocks	Gossans	Total	
1	--	--	--	--	--	--	--	--	--	None
2	1	0	½	1½	½	0	1	0	1½	Low
3	1	0	1	2	0	0	1	0	1	Moderate
4	1	0	½	1½	1	0	1	0	2	Low
5	1	0	1	2	1	0	1	0	2	Moderate
6	1	0	½	1½	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	½	1	2½	1	1	1	½	3½	Moderate
10	1	1	1	3	½	1	½	½	2½	High
11	1	1	1	3	0	1	½	1	2½	High
12	1	1	1	3	1	1	1	½	3½	High
13	1	½	0	1½	-1	0	0	0	-1	Low
14	1	½	0	1½	-1	0	0	0	-1	Low
15	1	½	½	2	-1	0	0	0	-1	Low

MERCURY REPLACEMENT DEPOSITS

By Benjamin F. Leonard and Theresa M. Cookro

Mercury occurs as cinnabar in replacement deposits in the north-central part of the Challis quadrangle in the vicinity of the Thunder Mountain cauldron complex. The host rocks are calcareous metasedimentary rocks intruded by Cretaceous and Tertiary granitic rocks. The cinnabar is in chalcedonic quartz replacing the metasedimentary rocks. High-angle faults striking 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 containing cinnabar strike about N. 35° E. through calcic marble. Total recorded production is twenty-seven 76-lb flasks of mercury in 1917–18 (U.S. Bureau of Mines, Spokane, Wash., unpub. data). 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 (James Ridenour, U.S. Bureau of Mines data base, Spokane, Wash., 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 dollars at the time of production, is approximately $3 million (U.S. Bureau of Mines, Spokane, Wash., unpub. data, 1983).

This report is taken from work by the authors at the three known deposits and from reports by Livingston (1919), Larsen and Livingston (1920), Schrader and Ross (1926), Currier (1935), and Bradley (1943). 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, supplemented by additional work, were summarized by Granger (written commun., 1945). A generalized version of the surface map by Granger and Shride was published by the U.S. Bureau of Mines (1943, fig. 3) in a report that also considers problems encountered in mining and milling Hermes ore.

DESCRIPTIVE MODEL

Ore body:

Size.—Tens to hundreds of feet wide; hundreds to thousands of feet long; tens to hundreds of feet thick.

Shape.—Irregularly shaped, chimneylike masses.

Tonnage and grade.—As much as several hundred thousand short tons of ore. Average grades are about 3 lb mercury/ton of ore.

Mineralogy:

Ore minerals.—Cinnabar.

Other minerals.—Trace electrum, quartz, chalcedony, sericite, pyrite, arsenopyrite, trace stibnite, dickite, kaolinite(?), montmorillonite, mixed-layer clays associated with chalcedony and potassium feldspar, vugs containing reddish chert or jasper.

The cinnabar (Schrader and Ross, 1926) occurs as small, irregularly shaped grains and thin coatings on pyrite grains and on surfaces and fillings of small open spaces, in narrow seams and in fractured jasperoid. Pyrite (A.E. Granger, written commun., 1945) is disseminated in the deposit; it is earlier than cinnabar and commonly 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 contained finely granular cinnabar, sparingly disseminated and showing 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 associated with patchy quartz displaying cockscomb textures. Cinnabar is found in colloform bands. At the Fern mine, chalcedony veins cut weathered calcic marble in which very fine grained aggregates of carbonate, chalcedony, clay, and limonite occur as sparse porphyroblasts that are pseudomorphs after tremolite or actinolite.

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 in small amounts.

Character of ore:

The best ore (A.E. 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 it is limited in depth on the south side by a large aplite dike.

Lithology of host rocks:

The district contains a series of tilted metasedimentary rocks consisting of quartzite, limestone, and schist intruded by Cretaceous granite and granodiorite, quartz porphyry, and aplitic dikes, and Tertiary rhyolitic dikes. The metasedimentary rocks strike northwest and dip 60°–85° 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, on the basis of regional stratigraphic and structural studies, to be Proterozoic and equivalent to the Yellowjacket Formation and Hoodoo Quartzite. 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 Company in massive dolomitic limestone as *Halysites* chain corals, and they concluded that the rock was Ordovician. Michael Taylor (U.S. Geological Survey, 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:

Slip faults striking N. 30° E. predominate (Fern mine), and the strike of the chalcedonic seams that contain cinnabar is about N. 35° E.; the seams dip northwest (Livingston, 1919; Schrader and Ross, 1926). The cinnabar at the Hermes mine (A.E. 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° W. and having nearly vertical bedding.

Geochemical and mineral indicators:

Mercury, antimony, and arsenic 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 striking N. 30° E. or N. 30°–50° W.
4. Presence of jasperoid or chalcedonic quartz or areas of intense silicification.

Permissive criteria:

1. Location within 5 mi of the edge of a caldera.
2. Presence of geochemical anomalies of mercury, antimony, or arsenic.
3. Presence of some sericitic alteration.
4. Presence of abundant clay minerals.

On the basis of these 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 31. We ranked area 3 as having high potential for the presence of undiscovered mercury deposits, area 2 as having moderate potential, and areas 1 and 4–9 as having low potential for these types of deposits. Area 3 contains the Hermes, Pretty Maid, and Fern mines. Area 2 has similar rock types, has undergone similar alteration, shows mercury, antimony, and arsenic anomalies, and contains cinnabar. The carbonate terrane of area 6 is near the edge of a cauldron complex, and areas designated 4 are other localities in the quadrangle where cinnabar has been recorded historically. Cinnabar with gold has been reported to be present in quartz veins in the largest block marked 4 on the map.

Table 31. Scores for recognition criteria for mercury replacement deposits in the Challis 1°× °quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion. See plate 14 for location of numbered areas]

Map area	Diagnostic criteria				Total	Permissive criteria				Total	Resource potential
	Presence of calcareous metasedimentary rocks	Presence of cinnabar	Presence of high-angle faults, especially striking N. 30° E. or N. 30-50° W.	Presence of jasperoid or chalcedonic quartz or areas of intense silicification		Within 5 mi 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		
1	½	0	0	0	½	-1	½	0	0	- ½	Low
2	1	½	½	½	2½	-1	1	½	½	1	Moderate
3	1	½	1	½	3	1	1	½	½	3	High
4	0	½	½	½	1½	- ½	½	½	½	1	Low
5	1	0	0	0	1	-1	½	0	0	- ½	Low
6	½	0	½	0	1	1	0	0	0	1	Low
7	½	0	½	½	1½	- ½	½	½	0	½	Low
8	½	½	0	0	1	1	0	0	0	1	Low
9	-1	0	½	½	0	½	½	½	½	2	Low

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 more than 0.75 mi wide and 8 mi 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. Isolated patches of zeolitically altered rock also occur in tuffs both within and outside the caldera margins. In some places, such as near Mosquito Flat Reservoir, these rocks are associated with intrusive rhyolite (Hardyman, 1985).

Zeolitically altered rocks are bleached to pale green and buff 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).

Hardyman (1985) suggested that the alteration was due to large volumes of hydrothermal fluids circulating within the medial fault system. Criss and others (1984) pointed out that these rocks are only moderately depleted in ^{18}O 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 were deposited in an open system (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 (1971) suggested a similar diagenetic origin for zeolitic tuff beds in the Oligocene Creede Formation in the San Juan volcanic field, Colorado.

Using the dimensions of the zeolite-bearing units, 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 considerable, but presently unknown, zeolite resources elsewhere in the quadrangle.

STRATIFORM DEPOSITS

PRECIOUS-METAL DEPOSITS IN EPICLASTIC SEDIMENTS

By Frederick S. Fisher and Kathleen M. Johnson

The Challis quadrangle hosts two examples of stratiform, volcanogenic, bulk-minable gold deposits developed in back-arc environments (Ivosevic, 1984), the Dewey deposit (described here) and the Sunnyside deposit (Fisher and Johnson, this volume p. 157). Both deposits are closely related to the development of the Thunder Mountain cauldron complex (Fisher and Johnson, this volume, p. 41), and each has some characteristics in common with the deposit at Round Mountain, Nev. (Tooker, 1985, p. 133 and 138). For purposes of this assessment, we have classified them separately because of differences in types of host rocks, as well as probable differences in genesis, suggested by markedly different geochemical signatures and by the importance of carbonaceous debris in only the Dewey deposit.

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 (U.S. Bureau of Mines, Spokane, Wash., unpub. data). 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, 200 ft wide, 140 ft thick.

Shape.—Bedded, stratabound, tabular.

Tonnage and grade.—1,428,000 tons at 0.13 oz gold/ton (Cater and others, 1973, p. 73).

Mineralogy:

Ore minerals.—Gold, silver, electrum, pyrargyrite.

Gangue minerals.—Pyrite, clays, rock fragments, carbonaceous debris (derived from plant materials).

Commodities:

Gold, silver.

Character of ore:

Ore minerals are concentrated in seams, cracks, and bedding plane laminations. Gold is fine grained, mostly <0.1 mm, but forms rare leaves or aggregates as large as several millimeters. It ranges from approximately 550 to 950 fine (B.F. Leonard, oral commun., 1985).

Lithology of host rocks:

The 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) described the beds of Dewey mine 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. Apparent concentration of ore along a fault striking about east to N. 30° W. (Shenon and Ross, 1936, p. 39).
3. Presence of ore in small-scale cracks, not distributed evenly through the rock.

Geochemical and mineral indicators:

Gold, silver, arsenic; pyrite, carbonaceous debris.

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, either geochemical anomalies, mines or prospects, or placer deposits.
2. Location within volcano-tectonic subsidence structures.
3. Presence of epiclastic sediments.
4. Presence of carbonaceous debris.

Permissive criteria:

1. Presence of shears associated with high-angle faults.
2. Presence of pyrite.
3. Presence of arsenic anomalies.
4. Presence of extensive areas of oxidized rock and limonitic soil.
5. Proximity to areas of 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 32). 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 that of the sediments that host the Dewey mine. If areas having 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. In area 1 no epiclastic sediments are known to exist, and, by definition, epiclastic sediments are essential for the existence of this deposit type.

Table 32. Scores for recognition criteria for precious-metal deposits in epiclastic sediments in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 15 for location of numbered areas]

Map area	Diagnostic criteria: Evidence of precious metals	Diagnostic criteria: Within volcano-tectonic subsidence structures	Diagnostic criteria: Presence of epiclastic sediments	Diagnostic criteria: Presence of carbonaceous debris	Total	Permissive criteria: Shears	Permissive criteria: Pyrite	Permissive criteria: Arsenic anomalies	Permissive criteria: Extensive zones of oxidized rock	Permissive criteria: Proximity to gold-silver mineralization	Permissive criteria: Proximity to high-angle structures	Total	Resource potential
1	--	--	--	--	--	--	--	--	--	--	--	--	None
2	½	-1	1	0	½	0	½	½	0	½	1	2½	Low
3	0	-1	1	½	½	0	½	0	0	0	1	½	Low
4	0	1	1	0	2	0	½	½	½	½	1	2	Low
5	1	1	1	½	3½	½	½	½	½	1	1	4	Moderate
6	1	1	1	1	4	1	½	½	½	1	1	4½	High

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 a stratiform bulk-minable gold deposit similar in some respects to the Dewey deposit (Fisher and Johnson, this volume, p. 154). 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, locally silicified, and stained with iron oxides. Sulfide minerals are sparse.

The Sunnyside tuff is a crystal-rich rhyolite. Away from the Sunnyside mine area (pl. 16) 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 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 the total phenocrysts, sanidine 50–70 percent, and biotite 0–3 percent; zircon, apatite, and opaque minerals comprise less than 1 percent of the phenocrysts.

Total gold and silver production from the Sunnyside mine is 5,237 oz and 3,909 oz, respectively (U.S. Bureau of Mines, Spokane, Wash., unpub. data, 1983). 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.—Tens to hundreds of feet wide and tens to hundreds of feet long; as much as 30 ft thick (averaging 10–15 ft).

Shape.—Bedded, stratabound, tabular.

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 about 1:3). Silver is also present as sparse acanthite and naumannite. Some molybdenum is 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) reported that the highest grade 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, nonwelded, porous rhyolite beneath much less permeable mudstone and clay-rich beds (Umpleby and Livingston, 1920, p. 5; Shenon and Ross, 1936, p. 41).
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.—Gold, silver, arsenic, and molybdenum are commonly concentrated in rocks within and near the ore zone. Copper, antimony, zinc, and tungsten are much less common but do occur in anomalous concentrations in samples of drill core from scattered localities in the mine area (Cater and others, 1973, p. 83; F.S. Fisher, unpub. data, 1981).

Mineralogical.—Clay minerals, sericite, illite, iron 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, either geochemical anomalies, mines or prospects, or placer deposits.
2. Location within volcanotectonic subsidence structures.
3. Presence of nonwelded rhyolitic tuff.
4. Location near (within 2 mi) high-angle faults.

Permissive criteria:

1. Extensive fracturing.
2. Presence of arsenic or molybdenum anomalies.
3. Extensive zones of oxidized rock.

Table 33. Scores for recognition criteria for precious-metal deposits in volcanic tuffs in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 16 for location of numbered areas]

Map area	Diagnostic criteria					Permissive criteria						
	Evidence of precious metals	Within volcano-tectonic subsidence structures	Presence of nonwelded rhyolitic tuff	Proximity to high-angle faults	Total	Fracturing	Arsenic and (or) molybdenum anomalies	Extensive zones of oxidized rock	Presence of impermeable barriers	Proximity to gold mineralization	Total	Resource potential
1	--	--	--	--	--	--	--	--	--	--	--	None
2	1	1	0	½	2½	½	1	½	0	½	2½	Low
3	½	1	1	½	3	0	½	0	½	½	1½	Moderate
4	1	1	1	1	4	½	0	0	½	1	2	High
5	½	1	1	½	3	0	0	0	½	½	1	Moderate
6	0	1	0	½	1½	0	0	0	0	0	0	Low
7	½	1	0	½	2	½	½	0	0	½	1½	Low
8	0	1	1	½	2½	0	0	0	0	0	0	Low
9	1	1	1	½	3½	0	½	0	0	½	1	High
10	1	1	1	1	4	½	1	½	½	1	3½	High
11	0	1	0	0	1	0	0	0	0	0	0	Low
12	½	1	0	½	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	½	1	1	0	2½	0	0	0	½	0	½	Low
16	½	1	0	1	2½	½	½	½	0	½	2	Low
17	0	1	1	0	2	0	0	0	½	0	½	Low
18	0	1	1	½	2½	0	0	0	½	0	½	Low
19	½	1	1	1	3½	½	0	½	½	½	2	High
20	½	1	0	½	2	0	0	0	0	½	½	Low
21	0	1	1	½	2½	0	0	0	½	0	½	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	½	- ½	0	0	0	0	0	0	Low

Map area	Diagnostic criteria: Evidence of precious metals	Within volcano-tectonic subsidence structures	Presence of nonwelded rhyolitic tuff	Proximity to high-angle faults	Total	Permissive criteria: Fracturing	Arsenic and (or) molybdenum anomalies	Extensive zones of oxidized rock	Presence of impermeable barriers	Proximity to gold mineralization	Total	Resource potential
26	0	-1	0	0	-1	0	0	0	0	0	0	Low
27	½	-1	0	1	½	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	½	0	0	0	½	Low
32	0	1	0	½	1½	0	0	0	0	0	0	Low
33	0	1	1	½	2½	0	0	0	½	0	½	Low
34	0	-1	1	½	½	0	0	0	½	0	½	Low
35	0	-1	1	½	½	0	0	0	½	0	½	Low
36	0	-1	0	1	0	0	0	0	0	0	0	Low
37	0	-1	1	1	1	0	0	0	½	0	½	Low
38	0	-1	0	½	- ½	0	0	0	0	0	0	Low
39	0	-1	0	½	- ½	0	0	0	0	0	0	Low
40	0	-1	0	0	-1	0	0	0	0	0	0	Low
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	½	0	½	Moderate
45	0	-1	1	1	1	0	0	0	½	0	½	Low
46	0	1	0	1	2	0	0	0	0	0	0	Low
47	0	1	0	½	1½	0	0	0	0	0	0	Low
48	0	1	0	½	1½	0	0	0	0	0	0	Low
49	½	1	0	½	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	½	0	½	Moderate
53	0	-1	0	1	0	0	0	0	0	0	0	Low
54	0	-1	0	½	- ½	0	0	0	0	0	0	Low
55	0	-1	1	1	1	0	0	0	½	0	½	Low

Table 33. Scores for recognition criteria for precious-metal deposits in volcanic tuffs in the Challis 1°×2° quadrangle, Idaho—Continued.

Map area	Diagnostic criteria					Permissive criteria						
	Evidence of precious metals	Within volcano-tectonic subsidence structures	Presence of nonwelded rhyolitic tuff	Proximity to high-angle faults	Total	Fracturing	Arsenic and (or) molybdenum anomalies	Extensive zones of oxidized rock	Presence of impermeable barriers	Proximity to gold mineralization	Total	Resource potential
56	0	-1	0	½	- ½	0	0	0	0	0	0	Low
57	0	-1	1	1	1	0	0	0	½	0	½	Low
58	½	-1	1	1	1½	0	0	0	½	0	½	Low
59	0	-1	0	1	0	0	0	0	0	0	0	Low
60	0	-1	1	1	1	0	0	0	½	0	½	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	½	0	½	Low
64	0	-1	0	1	0	0	0	0	0	0	0	Low
65	0	-1	1	1	1	0	0	0	½	0	½	Low
66	0	-1	0	1	0	0	0	0	0	0	0	Low
67	0	1	1	1	3	0	0	0	½	0	½	Moderate
68	0	1	1	1	3	0	0	0	½	0	½	Moderate
69	0	1	1	½	2½	0	0	0	½	0	½	Low
70	0	1	0	½	1½	0	0	0	0	0	0	Low
71	0	1	1	½	2½	0	0	0	½	0	½	Low
72	½	1	1	½	3	0	0	0	½	0	½	Moderate
73	0	1	1	½	2½	0	0	0	½	0	½	Low
74	0	1	1	0	2	0	0	0	½	0	½	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	½	1½	0	0	0	0	0	0	Low
78	0	1	0	½	1½	0	0	0	0	0	0	Low
79	0	-1	0	½	- ½	0	0	0	0	0	0	Low
80	0	-1	1	½	½	0	0	0	½	0	½	Low
81	0	1	1	½	2½	0	0	0	½	0	½	Low
82	1	1	1	1	4	0	0	0	½	½	1	High
83	0	1	0	½	1½	0	0	0	0	0	0	Low
84	0	1	0	½	1½	0	0	0	0	0	0	Low
85	1	1	0	1	3	½	½	½	0	1	2½	Moderate

Map area	Diagnostic criteria: Evidence of precious metals	Within volcano-tectonic subsidence structures	Presence of nonwelded rhyolitic tuff	Proximity to high-angle faults	Total	Permissive criteria: Fracturing	Arsenic and (or) molybdenum anomalies	Extensive zones of oxidized rock	Presence of impermeable barriers	Proximity to gold mineralization	Total	Resource potential
86	½	1	1	½	3	0	0	0	½	0	½	Moderate
87	0	1	0	½	1½	0	0	0	0	0	0	Low
88	0	1	0	0	1	0	0	0	0	0	0	Low
89	½	1	1	1	3½	½	0	½	½	½	2	High
90	0	1	0	1	2	0	0	0	0	0	0	Low
91	0	1	1	½	2½	0	0	½	½	0	1	Low
92	0	-1	1	1	1	0	0	½	½	0	1	Low
93	0	-1	1	0	0	0	0	0	½	0	½	Low
94	0	-1	0	0	-1	0	0	0	0	0	0	Low
95	0	-1	1	½	½	0	0	0	½	0	½	Low
96	0	-1	1	½	½	0	0	0	½	0	½	Low
97	0	-1	0	½	- ½	0	0	0	0	0	0	Low
98	½	-1	1	½	1	0	0	0	½	0	½	Low
99	0	-1	0	½	- ½	0	0	0	0	0	0	Low
100	½	-1	1	½	1	0	½	0	½	0	1	Low
101	0	-1	1	1	1	0	0	0	½	0	½	Low
102	0	-1	0	½	- ½	0	0	0	0	0	0	Low
103	0	-1	1	½	½	0	0	0	½	0	½	Low
104	0	-1	0	½	- ½	0	0	0	0	0	0	Low
105	½	-1	1	0	½	0	0	0	½	0	½	Low
106	0	-1	0	½	- ½	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	½	0	½	Low
109	0	-1	0	½	- ½	0	0	0	0	0	0	Low
110	½	-1	1	½	1	0	0	½	½	½	1½	Low
111	0	-1	1	1	1	0	0	0	½	0	½	Low

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 area of 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 33).

Areas 4, 9, 10, 19, 82, and 89 were ranked as having a high potential. 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, which were ranked as having moderate potential. 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, which were ranked as having low potential.

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 district. However, fluorite also occurs as veins, as 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 (Fisher and others, this volume, p. 116). 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.

Although extensive exploration has delineated very large resources of fluorspar as breccia-filling deposits in the Bayhorse–Garden Creek area, no production from them is known. 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 more than 3.2 million tons of ore that is 36 percent CaF_2 (Snyder, 1978). The third of these mineralized horizons occurs in the dolomite immediately below the Ramshorn Slate contact and is best developed on Keystone Mountain about 2.5 mi to the north of the Pacific Mine area (pl. 17) 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 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 event earlier and distinctly separate 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 length and width from a few tens of feet to several thousand feet. On Keystone Mountain scattered outcrops of a mineralized breccia zone, mostly covered 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 more than 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 more than 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, 1978). 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 variation in mineralization in the Bayhorse Dolomite (Chambers, 1966; Snyder, 1978). Local areas may average from 50 to 60 percent CaF_2, but the areal 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 potential of the entire district.

Mineralogy:

Ore minerals.—Fluorite; galena, tetrahedrite, and minor sphalerite occur locally and generally in small amounts in the breccia-filling deposits, and they 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 superimposed, so that the resulting ore body contains a mixed mineralogy.

Commodities:

Fluorite.

Character of ore:

Controlled by tabular, locally irregularly brecciated, horizons in the upper part of the Bayhorse Dolomite. The 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-mineralization 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 water. Gossans not prominent.

Lithology of 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, which 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, such as at the Pacific mine.

Controlling structures:

All of the known deposits are on the crest and flanks of the Bayhorse anticline. Most of the mineralized rock 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. Proximity to breccia horizons at or near a stratigraphic discontinuity at the top of the Bayhorse Dolomite.
3. Presence of steep faults, mostly north striking.
4. Proximity to Tertiary intrusive rocks.
5. Evidence of fluorite in nearby country rock.

Permissive criterion:

1. Presence of base- and precious-metal geochemical anomalies.

The five diagnostic criteria were used to divide the quadrangle into six areas (pl. 17). Each area was scored and ranked as to its potential—high, moderate, or low—for stratabound, stratiform breccia-controlled fluorspar deposits in carbonate rocks (table 34). Area 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 deposits similar to the one at the Pacific mine. It meets all of the diagnostic and permissive criteria. Areas 3 and 5 are scored as having moderate potential, and areas 2 and 6 were scored as having low potential for the occurrence of any ore bodies of this type.

Table 34. Scores for recognition criteria for stratabound, stratiform, breccia-controlled fluorspar deposits in carbonate rocks in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 17 for location of numbered areas]

Map area	Diagnostic criteria					Total	Permissive criterion	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	--	--	--	--	--	--	--	None
2	½	0	0	½	0	1	½	Low
3	1	0	1	0	1	3	1	Moderate
4	1	1	1	1	1	5	1	High
5	1	1	1	0	½	3½	1	Moderate
6	1	0	½	0	0	1½	½	Low

STRATIFORM BARITE DEPOSITS

By Wayne E. Hall and Thor H. Kiilsgaard

Stratiform barite deposits are common in siliceous sedimentary rocks of mid-Paleozoic age in North America (Brobst, 1973; Papke, 1984). Barite beds are a few inches to 50 ft thick and may extend over many acres. They are commonly 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°×2° quadrangle, 8 mi N. 80° W. of Hailey on Deer Creek. The deposit is described as a series of lenticular masses enclosed in rocks that are now mapped as Permian Dollarhide Formation (Umpleby and others, 1930; Kiilsgaard, 1950). North of Carey, in the Idaho Falls 1°×2° quadrangle, the Muldoon barite deposit is associated with limestone lenses in calcareous quartzitic beds of Mississippian Copper Basin Formation (Nelson and Ross, 1969). The 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 block of barite that extends about 100 ft east along the subsidiary fault. The open cut was driven on this faulted block. The sheared barite contains disseminated pyrite, sphalerite, and graphite. The west end of the open cut exposes stratiform barite dipping steeply to the west 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. A regional geochemical 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. There are anomalous concentrations of barium along Squaw Creek, Kinnikinic Creek, and Bayhorse Creek (fig. 4). Such high concentrations of barium in the nonmagnetic heavy-mineral fraction are presumed to be in the form of barite; it could come from barite gangue in base- and precious-metal deposits (Hobbs and others, this volume, p. 147).

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 (Simons, 1981, p. 147–149; Fisher and May, 1983). 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 consistently anomalous samples were collected in Mill Creek (fig. 5).

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 URANIUM DEPOSITS IN SEDIMENTARY ROCKS

By Kathleen M. Johnson and Theresa M. Cookro

Uranium deposits occur in Tertiary sedimentary rocks 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. These deposits are similar to deposits classified as basal-type deposits by Boyle (1982) and are therefore a variety of sandstone-type uranium deposit.

Production from the Coal Creek #1 and #4, Deer Strike–Elk, East Basin, and Shorty #2 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 1970's (Wopat and others, 1980).

DESCRIPTIVE MODEL

Ore body:

Size.—Hundreds of feet long; tens of feet wide; tens of feet thick.

Shape.—Lenticular to irregular.

Tonnage and grade.—Thousands of tons of ore in the range of tenths of a percent U_3O_8.

Mineralogy:

Ore minerals.—Uraninite, coffinite, autunite.

Accessory minerals.—Pyrite, marcasite.

Gangue minerals.—Quartz, feldspar, 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 claystone, siltstone, and arkosic sandstone containing 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, mineral, and other indicators:

Uranium, arsenic, iron, antimony; pyrite, minor marcasite. High uranium values are commonly associated with high concentrations of carbonaceous debris. 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) reported that some of the deposits at Basin Creek were elongated by later fault offset; 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 Tertiary sedimentary rocks originating in fluvial environments, for example, in 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 arsenic, iron, and antimony.
2. High permeability.

We plotted these criteria on the quadrangle map and divided the map into 11 types of areas on the basis of 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 35).

Most of the areas outlined on plate 18 are those in which appropriate Tertiary sedimentary rocks exist as shown on the geologic map (Fisher and others, 1992, in pocket). We are unable to estimate the likelihood that appropriate sedimentary rocks occur 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. Terrane like this could exist in other parts of the quadrangle that are covered by younger sedimentary or extrusive volcanic rocks.

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 1950's and late 1970's. Those areas listed as having low potential (1–5, 7, 9, 10) meet some of the diagnostic criteria, but not enough to suggest the likelihood of more deposits.

Table 35. Scores for recognition criteria for stratiform uranium deposits in sedimentary rocks in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; ½, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 18 for location of numbered areas]

Map area	Diagnostic criteria: Presence of Tertiary sedimentary rocks	Diagnostic criteria: Evidence of uranium mineralization	Diagnostic criteria: Proximity to high-angle structures	Diagnostic criteria: Abundance of carbonaceous material	Total	Permissive criteria: Geochemical anomalies of As, Fe, Sb	Permissive criteria: 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	½	1	1½	-1	0	-1	Low
5	1	-1	½	-1	- ½	-1	0	-1	Low
6	½	1	1	0	2½	-1	1	0	Moderate
7	1	-1	½	-1	- ½	1	0	1	Low
8	1	-1	½	1	1½	1	0	1	Low
9	1	1	1	1	4	1	1	2	Moderate
10	1	1	1	-1	2	½	0	½	Low
11	--	--	--	--	--	--	--	--	None

STRATABOUND, SYNGENETIC DEPOSITS

STRATABOUND VANADIUM DEPOSITS

By Wayne E. Hall

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 vast resource for possible future use. In order to evaluate it as a possible vanadium resource, Fisher and May (1983) made a reconnaissance geochemical study. Their results are given in the frequency-distribution plots of 257 random chip samples taken from 20-ft stratigraphic intervals (fig. 27). This sampling was done in the vicinity of the Salmon River between Thompson Creek and Slate Creek (fig. 5). They found 26 percent of the samples contained anomalous concentrations of vanadium (>1,000 ppm) and several samples contained 0.5 to >1 percent vanadium. Most samples enriched in vanadium were also enriched in molybdenum, silver, and zinc. The highest concentrations of vanadium are found along Slate Creek and Mill Creek within the belt of anomalous zinc. This belt also contains anomalous concentrations of lead, barium, and molybdenum. No work has been done to trace along strike the highly anomalous vanadiferous beds. Analysis of stream-sediment and rock samples from the black shale terrane (Tschanz and Kiilsgaard, 1986, table 2) indicates vanadium is in anomalous concentrations in the same N. 10° E.-trending belt as is zinc: a belt extending from Washington Basin to Squaw Creek and including the Slate Creek and Mill Creek drainage basins (fig. 5).

In contrast, stream-sediment samples from the Ramshorn Slate and Grand Prize Formation had no anomalous concentrations of vanadium. The only anomalous concentrations of vanadium in panned concentrates were in Thompson Creek downstream from the Tungsten Jim mine (Tschanz and Kiilsgaard, 1986, table 2). Only one of 135 random chip samples collected from the black shale terrane in the Hailey 1°×2° quadrangle contained as much as 1,000 ppm vanadium; this was from the Milligen Formation at the Triumph mine.

The Devonian 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 that contained 1,500 to 3,700 ppm vanadium was outlined in the Woodruff Formation (Desborough and Poole, 1983).

DESCRIPTIVE MODEL

Ore body:

Size.—Thousands of feet long; thousands of feet wide; hundreds of feet thick.

Shape.—Tabular deposits having gradational contacts along strike, width, and depth.

Tonnage.—Large resource (>1 million 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 products:

The oxidized rocks are light colored (pale brown, red, or yellow) 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 recognized on weathered surfaces.

Lithology of host rocks:

Black, fine-grained, siliceous mudstone, siltite, micritic limestone, chert, and dolomitic siltstone.

Alteration:

Veinlets of chalcedony and fractures filled with opaline silica of probable diagenetic origin (Desborough and Poole, 1983).

Geochemical and mineral indicators:

Zinc, molybdenum, nickel, chromium, and especially selenium and arsenic; 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. 5).

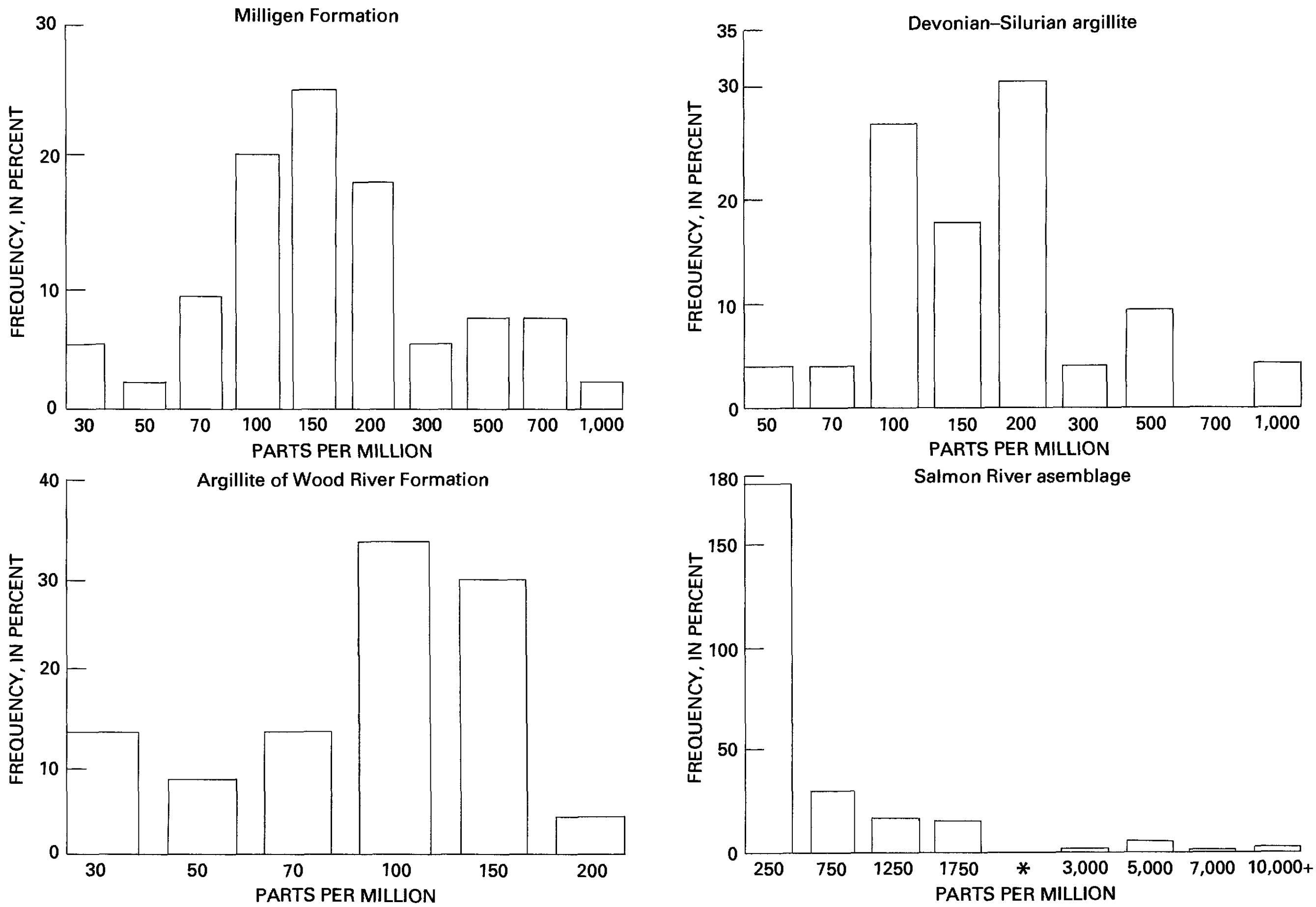

Figure 27. Histograms for vanadium concentrations in the Milligen Formation, undivided Devonian and Silurian argillite, argillite of the Wood River Formation, and Salmon River assemblage, central Idaho.

RESOURCE ASSESSMENT

From the descriptive model presented above, three diagnostic and seven permissive recognition criteria are defined:

Diagnostic criteria:

1. Presence of rocks of black shale terrane.
2. Evidence of anomalous concentrations of vanadium in rock or stream-sediment samples.
3. Evidence of synsedimentary structures, such as down-dropped blocks or deep-seated faults, that could localize metalliferous hydrothermal brines.

Permissive criteria:

1. Presence of rocks of Salmon River assemblage.
2. Presence of pink vanadium bloom in outcrop.
3. Evidence of zinc anomalies in rock, panned-concentrate, or stream-sediment samples.
4. Evidence of molybdenum anomalies in rock, panned-concentrate, or stream-sediment samples.
5. Evidence of lead anomalies in rock, panned-concentrate, or stream-sediment samples.
6. Evidence of barium anomalies in rock, panned-concentrate, or stream-sediment samples.
7. Presence of oxidized strata bleached to light gray and light brown.

The quadrangle was divided into 11 areas (pl. 19) whose potential for stratiform vanadium deposits ranges from low to high. Each area was evaluated and given semi-quantitative scores for each of the diagnostic and permissive criteria (table 36).

We consider that the potential for an undiscovered multimillion ton resource containing greater than 0.5 percent vanadium is high in area 1. The areas classified as having moderate potential for large, low-grade vanadium resources, areas 2–6, are in black shale terrane but contain no widespread concentrations of anomalous vanadium. Areas 7–10 have low potential. Area 11 has no potential for stratiform vanadium deposits because the diagnostic host rocks are absent.

Table 36. Scores for recognition criteria for stratabound vanadium deposits in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 19 for location of numbered areas]

Map area	Diagnostic criteria				Permissive criteria								
	Black shale terrane	Vanadium anomalies	Synsedimentary structures	Total	Salmon River assemblage	Pink vanadium bloom	Zinc anomalies	Molybdenum anomalies	Lead anomalies	Barium anomalies	Bleached, oxidized strata	Total	Resource potential
1	1	1	1	3	1	1	1	1	1	1	½	5½	High
2	1	½	0	1½	1	0	½	1	½	0	0	3	Moderate
3	1	½	0	1½	1	0	½	½	-1	1	0	2	Moderate
4	1	½	0	1½	-1	0	0	½	0	0	0	- ½	Moderate
5	1	½	0	1½	-1	0	1	-1	1	1	0	1	Moderate
6	1	0	0	1	-1	0	0	-1	-1	½	0	-2½	Moderate
7	0	0	0	0	-1	0	½	-1	-1	1	0	-1½	Low
8	0	0	0	0	-1	0	0	0	-1	½	0	-1½	Low
9	0	-1	0	-1	-1	0	½	½	-1	½	0	- ½	Low
10	0	½	0	½	-1	0	0	-1	½	½	0	-1	Low
11	--	--	--	--	--	--	--	--	--	--	--	--	None

STRATABOUND, SYNGENETIC DEPOSITS OF BASE AND PRECIOUS METALS IN ARGILLITE AND MICRITIC LIMESTONE

By Wayne E. Hall

Desborough and Poole (1983) recently described the geologic environment and the metal concentrations of upper Paleozoic black shales in the Western United States, including three depositional settings that are favorable for organic-rich metalliferous marine strata: (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. The study of the Salmon River assemblage by Fisher and May (1983, p. 5) showed the following enrichment compared to average black shales of the United States:

Metal	*Anomalous level (ppm) (from 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 to be present in the Challis quadrangle at the Hoodoo and Livingston mines. Widespread anomalous concentrations of zinc occur in the Salmon River assemblage in the Slate Creek–Mill Creek area, which encompasses both the Hoodoo and Livingston mines (fig. 5). 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 Kiilsgaard, 1986, fig. 12, table 2). These samples containing anomalous concentrations of zinc are from localities that trend N. 20° E. from the Hoodoo mine for 8 mi in a belt 3 mi wide (fig. 5). 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. 5). 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 Hoodoo ore body ranges from a few feet to 38 ft thick and is 1,725 ft long and at least 885 ft deep (Van Noy and others, 1986, p. 264). The extent of the bedded zinc-rich ore at the Livingston mine is not known because mining has been concentrated on locally remobilized ore at the intersections of large felsic dikes with the Livingston vein.

Shape.—Tabular, stratiform ore bodies. Contacts with country rock are sharp.

Tonnage and grade.—From tens of thousands to tens of millions of tons. The grade of ore is mostly less than 12 percent total zinc and lead, the zinc greatly predominating over lead. Samples from the Hoodoo ore body indicate a grade of 11 percent zinc and 0.47 percent lead (Van Noy and others, 1986). The sphalerite contains 0.6 percent cadmium and a little silver. Stratiform ore in the Milligen Formation at the Triumph mine (43°38′ N., 114°16′ W., Hailey 1°×2° quadrangle) in the Wood River district contains 13 percent zinc, 5.9 percent lead, and 6.5 oz/ton silver (Kiilsgaard, 1950).

Mineralogy:

Ore minerals.—Sphalerite, galena.

Gangue minerals.—Pyrite, pyrrhotite, arsenopyrite, quartz, calcite, clay minerals, tremolite.

Lithology of host rock:

Black, siliceous, carbonaceous argillite and fine- to medium-grained gray limestone or micritic carbonaceous limestone that were deposited in a euxinic environment.

Alteration:

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. The black shale terrane was altered by widespread 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.

Geochemical and mineral indicators:

Zinc, lead, barium, silver; disseminated pyrite and sphalerite in the black shale or in faults that may represent feeder zones adjacent to or below stratiform ore.

Controlling structures:

Grabens in either (1) epicratonic marine basins or embayments; or (2) continental shelf and foreland basins; or (3) continental-rise and marginal basins. Ore was deposited in active tectonic environments from metal-bearing geothermal brines that rose to the sea floor along deep-seated fault zones. The brines were localized within synsedimentary downdropped troughs or basins.

Geophysical indicators:

Geophysical methods were employed with some success on similar deposits in Selwyn Basin (Carne and Cathro, 1982). The shallow Anvil Camp deposits could be detected in magnetic, electromagnetic, and gravity surveys (Brock, 1973). An electromagnetic investigation of the Mill Creek zinc anomaly was made by Tschanz and Frischknecht (1986). They found several good conductor horizons but concluded that these horizons did not indicate unequivocally any sulfide bodies.

RESOURCE ASSESSMENT

From the descriptive model presented above, three diagnostic and eight permissive recognition criteria are defined.

Diagnostic criteria:

1. Location in a black shale terrane.
2. Anomalous concentrations of zinc and (or) lead.
3. Evidence of deep-seated fault or synsedimentary structures that could localize metalliferous hydrothermal-brines.

Permissive criteria:

1. Presence of barite or barite anomalies.
2. Anomalous concentrations of silver and (or) cadmium.
3. Presence of gossan.
4. Presence of highly carbonaceous argillite or micritic limestone.
5. Disseminated pyrite and sphalerite in argillite, in 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 11 areas (pl. 20), 10 of which range from low to high in their potential for stratabound syngenetic zinc-lead-silver deposits. Each area was evaluated and given a semiquantitative score for each of the diagnostic and permissive criteria (table 37).

Areas 1 and 5 have high potential; both contain productive base- and precious-metal mines (pl. 20). Area 1 contains two known base- and precious-metal deposits—at the Livingston mine and the Hoodoo mine—in a north-northeast-trending area showing widespread zinc, lead, and silver anomalies. Area 5 contains productive replacement deposits of base and precious metals at the Pacific, Beardsley, Excelsior, and Riverview mines. Attention should be directed to Mill Creek, which produced stream-sediment samples containing highly anomalous concentrations of zinc, but where no deposits are known. Area 5 contains no known stratiform zinc-lead-silver mineralization; however, because all the diagnostic criteria are at least satisfied, it is considered to have high potential for these deposits.

Areas 2–4 and 6–8 are classified as having moderate potential for stratabound syngenetic zinc-lead-silver deposits and are all in black shale terrane, but no widespread concentrations of zinc, lead, or silver were detected by 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 ore minerals may be altered to oxide minerals at the surface, but they are evident in drill cores.

To the best of our knowledge, in areas 9 and 10 rocks of the black shale terrane are not exposed, there is little or no evidence of deep-seated faulting, and there are no anomalous concentrations of zinc or lead. Therefore, low scores for diagnostic criteria were obtained and areas 9 and 10 are classified as having low potential for deposits of this type.

Area 11 has no potential for deposits of this type because it is outside the black shale terrane.

Table 37. Scores for recognition criteria for stratabound, syngenetic deposits of precious and base metals in argillite and micritic limestone in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; -1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 20 for location of numbered areas]

Map area	Diagnostic criteria				Permissive criteria									
	Black shale terrane	Zinc or lead anomalies	Evidence of deep-seated fault or syn-sedimentary structures	Total	Presence of barite or barite anomaly	Silver or cadmium anomalies	Gossan	Carbona-ceous argillite or micritic limestone	Dissemi-nated pyrite or sphal-erite	Salmon River assemblage	Marine black shale basinal setting	Presence of base- and precious-metal vein deposits	Total	Resource potential
1	1	1	1	3	1	1	1	1	1	1	1	1	8	High
2	1	½	0	1½	½	0	½	1	1	1	1	½	5½	Moderate
3	1	½	0	1½	0	0	½	1	1	1	1	-1	3½	Moderate
4	1	½	0	1½	0	½	0	1	1	0	0	½	3	Moderate
5	1	½	½	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	½	0	1½	0	½	0	1	1	0	0	0	2½	Moderate
8	1	0	0	1	½	½	0	0	0	-1	0	0	0	Moderate
9	0	-1	0	-1	½	½		0	0	-1	0	0	0	Low
10	0	½	0	½	½	½		0	½	-1	0	½	0	Low
11	--	--	--	--	--	--	--	--	--	--	--	--	--	None

STRATABOUND, SYNGENETIC COBALT-COPPER DEPOSITS

By Kathleen M. Johnson and Earl H. Bennett[10]

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 deposits are at the Blackbird mine, about 7.5 mi north of the quadrangle boundary (45°07′ N., 114°20′ W.) in the Elk City 1°×2° quadrangle. The Blackbird deposits are the most readily available source of cobalt in the United States, having published reserves of 5.0 million tonnes of mining reserves and 7.3 million tonnes indicated reserves (Nash and Hahn, 1986, p. 2).

Three types of cobalt-copper deposits are known to be present 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 commonly closely associated with metamorphosed mafic strata that probably were volcaniclastic rocks. At Iron Creek, lodes of cobaltiferous pyrite, containing variable amounts of chalcopyrite, occur in fine-grained clastic metasedimentary rocks 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 were 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. 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) demonstrated 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). We did not consider Twin Peaks in constructing the descriptive model or in 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 mineralized rocks 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 was reported by Nash and Hahn (1986). Our description is summarized from the references listed above, from Anderson (1943b), Earhart (1986), Modreski (1985), and from work at Blackbird by the second author of this section (Bennett, 1977).

DESCRIPTIVE MODEL

Ore body:

Size.—Lodes occur as individual lenses tens of feet thick and thousands of feet long. At Blackbird at least 12 lodes occur in an area of 3.5 mi^2.

Shape.—Irregular pods and lenses, generally separated by barren metasedimentary rock. Multiple vertically oriented lenses can occur over an interval of about 300 ft.

Tonnage and grade.—Several million tons of ore containing tenths of a percent cobalt and several percent copper.

Mineralogy:

Major ore minerals.—Cobaltite and chalcopyrite.

Minor but significant minerals.—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 having cataclastic textures along shear zones. Pyrite locally has colloform structure.

Lithology of host rocks:

Fine-grained metasedimentary rocks (argillite, siltite, and quartzite), and mafic volcaniclastic rocks. Metasedimentary rocks may have large volcanogenic component. Sedimentary structures are abundant, including graded

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[10]Idaho Geological Survey.

beds, silt-sand couplets, flute casts, load structures, slumped beds, and sand dikelets.

Alteration:

Silicification.

Weathering products:

Forms prominent gossans where sulfide- and sulfarsenide-rich rocks crop out.

Geochemical indicators:

Enriched in iron, arsenic, boron, bismuth, cobalt, copper, and gold. Low in lead, zinc, and silver. Depleted in calcium and sodium.

Controls on formation of ore:

1. Ore commonly occupies structures that disrupt bedding. Regional distribution of ore closely follows distribution of mafic volcaniclastic rock.
2. Basinal growth faults appear to have influenced location of lodes by determining the shape of the basin, and thus the locus of deposition of mafic volcaniclastic rocks, and by providing pathways for mafic intrusions and eruptions and hydrothermal fluids.

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. Presence of sediments deposited below wave base.
3. Evidence of synsedimentary mafic intrusions or eruptions.
4. Anomalous concentrations of iron, cobalt, copper, arsenic, and bismuth.

Permissive criteria:

1. Evidence of silicification and chloritization.
2. Anomalous concentrations of boron or gold.
3. Presence of gossans.
4. Presence of basinal growth faults.

The recognition criteria were used to divide the quadrangle into 12 types of areas (pl. 21). Eleven of these were scored and ranked for their potential for undiscovered resources of stratabound syngenetic cobalt-copper deposits (table 38). 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 have some characteristics associated with these deposits, and area 2 also contains the small deposit at Iron Creek.

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, 1992, in pocket), the apparent absence of syngenetic mafic intrusions in Paleozoic metasedimentary rocks, and the lack of appropriate geochemical signatures in most areas.

Table 38. Scores for recognition criteria for stratabound, syngenetic cobalt-copper deposits in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 21 for location of numbered areas]

Map area	Diagnostic criteria: Fine-grained metasedimentary rocks	Sediments deposited below wave base	Synsedimentary mafic rocks	Fe, Co, Cu, As, and Bi anomalies	Total	Permissive criteria: Silicification and chloritization	B, Au anomalies	Presence of gossans	Presence of basinal growth faults	Total	Resource potential
1	1	-1	0	1	1	1	½	½	0	2	Low
2	1	0	½	1	2½	1	1	1	0	3	Moderate
3	1	½	½	½	2½	½	½	½	0	1½	Moderate
4	1	0	0	0	1	0	½	0	0	½	Low
5	1	0	0	½	1½	0	0	0	0	0	Low
6	1	0	0	0	1	0	0	½	0	½	Low
7	1	0	0	0	1	0	0	0	0	0	Low
8	1	½	0	½	2	½	½	1	0	2	Low
9	1	0	0	½	1½	0	½	0	0	½	Low
10	1	1	0	0	2	½	½	½	1	2½	Low
11	1	1	0	0	2	½	½	0	0	1	Low
12	--	--	--	--	--	--	--	--	--	--	None

PLACER DEPOSITS

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, five have produced more than 1,000 oz and one more than 10,000 oz (table 39). Estimated total gold production from these and smaller 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 and a few years later in the Yankee Fork, Loon Creek, Yellowjacket, and Gravel Range districts. Placer gold was found in the Thunder Mountain district in 1894. Small-scale placer operations have waxed and waned, following the price of gold. 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 the gradient decreases or where the stream flow is slowed for any reason. Most of the placer gold in the Challis quadrangle is in fluvial 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 precious-metal lode deposits.

Gold grains range in size from a few millimeters to more than 1 in. in diameter. For example, Tschanz and Kiilsgaard (1986, p. 96) reported 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 1 in. 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 were 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. 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 100 feet.

Shape.—Irregular, generally blanketlike; may be present 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 a few hundredths to a few thousandths 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 byproducts are radioactive minerals, niobium, tantalum, and rare-earth elements from associated black sands.

Character of ore:

Size of gold ranges from less than 1 mm to more than 2.5 cm in diameter. Fineness ranges from 590 to 930. Most districts had an average reported fineness of about 760.

Lithology of host rocks:

Alluvium, principally Pleistocene in age, consisting of sand, gravel, and boulders. Most clasts are less than 2 ft in diameter. Some deposits contain 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.

Table 39. Placer deposits having production of more than 100 oz gold, Challis 1°×2° quadrangle, Idaho.

[Sources of data: Cater and others (1973); Choate (1962;) Umpleby (1913a, b;) Umpleby and Livingston (1920); and unpublished records of U.S. Bureau of Mines, Spokane, Wash. --, no data]

Placer name	Au (oz)	Ag (oz)	Yardage	Value (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	--

Table 40. Scores for recognition criteria for gold placer deposits in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion; --, criterion not scored because of absence of geologic feature in area being considered that is essential to the occurrence of the type of ore deposit being assessed. See plate 22 for location of numbered areas]

Map area	Diagnostic criteria: Evidence of precious metals	Diagnostic criteria: Proximity to lodes	Diagnostic criteria: Presence of alluvium	Total	Permissive criteria: Pleistocene alluvium	Permissive criteria: Source streams eroding lodes	Permissive criteria: Tested resource	Total	Resource potential
1	½	-1	½	0	½	-1	0	- ½	Low
2	½	½	½	1½	½	½	0	1	Low
3	½	-1	½	0	1	-1	0	0	Low
4	½	-1	½	0	1	-1	0	0	Low
5	½	½	½	1½	½	½	0	1	Low
6	1	1	½	2½	½	1	0	1½	Moderate
7	1	1	1	3	½	1	½	2	High
8	1	½	½	2	½	1	0	1½	Low
9	1	1	½	2½	½	1	½	2	Moderate
10	1	½	½	2	½	½	½	1½	Low
11	1	1	½	2½	½	1	0	1½	Moderate
12	½	-1	1	½	½	-1	½	0	Low
13	½	-1	½	0	0	-1	0	-1	Low
14	1	1	½	2½	½	1	0	1½	Moderate
15	½	-1	½	0	½	-1	0	- ½	Low
16	½	-1	½	0	0	-1	0	-1	Low
17	½	-1	½	0	0	-1	0	-1	Low
18	½	1	½	2	½	1	0	1½	Low
19	1	½	1	2½	½	1	½	2	Moderate
20	½	1	½	2	½	½	0	1	Low
21	1	1	1	3	1	1	1	3	High
22	½	1	½	2	½	½	½	1½	Low
23	1	½	1	2½	½	-1	½	0	Moderate
24	½	-1	½	0	½	-1	0	- ½	Low
25	1	½	1	2½	1	-1	0	0	Moderate
26	½	-1	½	0	½	-1	0	- ½	Low
27	1	-1	1	1	1	-1	0	0	Low
28	½	-1	1	½	1	-1	0	0	Low
29	½	½	½	1½	½	-1	0	- ½	Low
30	1	1	1	3	1	1	1	3	High

Map area	Diagnostic criteria: Evidence of precious metals	Proximity to lodes	Presence of alluvium	Total	Permissive criteria: Pleistocene alluvium	Source streams eroding lodes	Tested resource	Total	Resource potential
31	½	-1	½	0	½	-1	0	- ½	Low
32	½	1	½	2	½	1	0	1½	Low
33	½	-1	½	0	0	-1	0	-1	Low
34	½	½	½	1½	0	0	0	0	Low
35	½	½	½	1½	0	0	0	0	Low
36	½	½	½	1½	½	½	0	1	Low
37	½	½	1	2	1	½	0	1½	Low
38	1	1	½	2½	1	0	0	1	Moderate
39	½	½	1	2	1	½	½	2	Low
40	½	-1	1	½	1	-1	½	½	Low
41	½	-1	1	½	1	-1	½	½	Low
42	1	1	1	3	1	1	½	2½	High
43	1	1	1	3	1	1	1	3	High
44	0	½	½	1	1	½	0	1½	Low
45	0	½	½	1	1	½	0	1½	Low
46	½	½	½	1½	1	½	½	2	Low
47	½	-1	½	0	½	-1	½	0	Low
48	½	-1	½	0	½	-1	½	0	Low
49	½	-1	½	0	½	-1	½	0	Low
50	½	-1	½	0	½	-1	½	0	Low
51	½	-1	½	0	½	-1	½	0	Low
52	1	½	1	2½	½	½	½	1½	Moderate
53	½	-1	½	0	½	-1	0	- ½	Low
54	½	½	½	1½	½	½	0	1	Low
55	1	½	½	2	1	½	0	1½	Low
56	1	1	1	3	1	1	½	2½	High
57	½	½	½	1½	½	½	0	1	Low
58	--	--	--	--	--	--	--	--	None

Controls on formation of ore:

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 channels and gravel depths for large deposits, but none is available.

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, either geochemical anomalies, lode mines or prospects, or placer deposits.
2. Within 5 mi downstream of known precious-metal lode deposits.
3. Presence of alluvium. At our map scale (1:250,000) many areas of alluvium large enough to contain productive placers are 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 deposits from 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 were reported in Cater and others (1973), Kiilsgaard and others (1970), Van Noy and others (1986), and Choate (1962).

On the basis of these criteria, 57 areas were delineated within the Challis quadrangle (pl. 22) and each area was ranked by scoring it against the individual diagnostic and permissive criteria. The scores are shown in table 40. 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 880, there is also a significant resource of silver in these deposits. In area 43, the U.S. Bureau of Mines (Van Noy and others, 1986, p. 467, table 37) estimated that placers in Valley Creek contain 10 million cubic yards of gravel with a gold content ranging from a trace to 249.9 cents per cubic yard and averaging 38.1 cents (at $128.50 per oz of gold), for a calculated total of 29,650 oz of gold. Total conditional resources in area 43 include 40,304 oz of gold. In area 42, total conditional resources equal 5,312 oz, contained in Robinson Bar, Easy Bar, Treon Creek Bar, Cold Creek Bar, and Burnt Bar, all located along the Salmon River (Van Noy and others, 1986, p. 467). In the Yankee Fork district (area 30), drilling prior to dredging in the 1940's indicated a gold content worth $11 million. 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 having an average grade of 0.0035 oz of gold per cubic yard (J.W. 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 (Kiilsgaard and others, 1970; Cater and others, 1973; Van Noy and others, 1986). 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 is 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.

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" means 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).

These black-sand placer 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 41) 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).

The gravel 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 do the coarser sand and gravel. Presently degrading stream beds may contain larger boulders, transported by floods, but boulders are uncommon in the deep 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 and leave 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 was detected to a depth of 120 ft, the deepest hole drilled, although a more consistent content of monazite was found at depths ranging from 15 to 55 ft (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 ft 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 subject 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 commonly 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 ($FeOFe_2O_3$) 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 of 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 41). Ilmenite from nine deposits in Long Valley averaged 46.1 percent TiO_2 (Storch and Holt, 1963). Other black-sand minerals in Idaho placer deposits were discussed by Savage (1961).

Monazite, a rare-earth phosphate mineral whose principal components are cerium, lanthanum, and neodymium 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

Table 41. Radioactive black-sand placer deposits that have been explored by drilling, Challis 1°×2° quadrangle, Idaho.

Deposit	Area (sq yd)	Average depth (yd)	Volume (cu yd)	Average mineral content (lbs/cu yd)				Monazite		Resources of ThO_2 in monazite (short tons)
				Ilmenite	Garnet	Zircon	Monazite	ThO_2 (pct.)	U_3O_8 (pct.)	
Deposits that contain 0.50 lb or more monazite per cubic yard of alluvium										
Big Creek[1,9]	3,570,000	20	71,400,000	14	2.10	0.70	1.50	4.2	0.13	2,250
Pearsol Creek[2,9]	6,500,000	20	130,900,000	16	0.40	.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	[6]4.1	--	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 Meadow)[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	[6]4.2		50
Gold Creek-Williams Creek[9]	1,600,000	15	24,000,000	4	--	--	.90	[6]4.2	--	450
								Total	....	21,080
Deposits that contain less than 0.50 lb monazite per cubic yard of alluvium										
Paddy Flat[5]	2,400,000	16	38,400,000	12	3.0	--	.40	[6]4.2	.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	0.6	--	--	.10	[6]4.2	--	80
Deadwood Valley[9]	16,400,000	10	164,000,000	4	.4	.10	.10	[6]4.2	--	340
Peace Valley[9]	2,500,000	4	10,000,000	2	--	--	.30	[6]4.2	--	60
Garden Valley[9]	9,000,000	27	243,000,000	2	--	--	.20	[6]4.2	--	1,020
Stolle Meadows[9]	3,900,000	15	58,500,000	2	--	--	.20	[6]4.2	--	250
Kelly Creek[9]	24,000	5	120,000	3			.10	[6]4.2	--	--
Stanley Creek[9]	1,400,000	15	21,000,000	3	--		.20	[6]4.2	--	90
Payette Placer[10]	3,240,000	25	81,000,000	[11]11	[12]4					
								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 U.S. Department of Defense Minerals Exploration Administration data.
[6]Estimate.
[7]Kline and others, 1951b.
[8]R.D. Porter, written commun., 1985.
[9]Storch and Holt, 1963.
[10]Kiilsgaard and others, 1970.
[11]Black sand, not ilmenite.
[12]Total nonmagnetic fraction.

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 lb 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 content of monazite in some of the placers is shown in table 41. 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 cubic yards 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, deposits 16–18) 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 showed 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) described euxenite crystals and grains in upstream parts of Bear Valley and noted that size of the grains decreases by three to four times within the first mile of downstream transport. The reduction in grain size 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 the 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 radioactivity surveys 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 that is partially covered by Pleistocene glacial moraine and that contains gravels derived from Tertiary intrusive rock 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:

Oxide	*Percent*
Nb_2O_5	27.07
Ta_2O_5	3.01
TiO_2	20.91
U_3O_8	10.25
ThO_2	2.80
SiO_2	3.24
$RE_2O_3+Y_2O_3$	18.86
P_2O_5	0.98
MnO_2	1.00
MgO	0.44
Fe_2O_3	5.30
Al_2O_3	1.07
Unclassified	5.07
Total	100.00

Columbite:

Oxide	*Percent*
Nb_2O_5	60.84
Ta_2O_5	7.64
TiO_2	2.09
U_3O_8	1.50
Re_2O_3	1.89
MnO_2	7.91
Fe_2O_3	11.74
Unclassified	6.39
Total	100.00

According to Porter (written commun., 1985) the rare earth ($Re_2O_3+Y_2O_3$) composition of euxenite is as follows:

Oxide	*Percent*
Y_2O_3	57.9
La_2O_3	2.4
CeO_2	5.9
Pr_6O_{11}	0.8
Nd_2O_3	3.8
Sm_2O_3	2.2
Eu_2O_3	0.1
Gd_2O_3	5.9
Tb_4O_7	1.3
Dy_2O_3	7.4
Ho_2O_3	1.9
Er_2O_3	3.3
Tm_2O_3	0.9
Yb_2O_3	3.2
Lu_2O_3	0.4

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. Dredging capacity of the two dredges was 7,000–8,000 cubic yards per day. Approximately 6,500,000 cubic yards 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 of 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 Corporation fulfilled their contract to provide 1,050,000 lbs containing 90 percent niobium-tantalum pentoxides to the U.S. Government General Services Administration stockpile. Porter Brothers Corporation estimates that about 67,000,000 cubic yards of dredgable alluvium remains at Big Meadow, the average grade of which is about 0.40 lbs of euxenite and columbite and 0.75 lbs of monazite per cubic yard (R.B. Porter, written commun., 1985).

Most of the deposits listed in table 41 as containing 0.50 lbs or more 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).

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 41. Deposits that contain 0.5 lb or more monazite per cubic yard are shown separately because they would be the most likely candidates for exploitation, should economic conditions make dredging feasible. Volume estimates for the deposits are considered conservative because 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 if the price of thorium is very high. Present dredge laws and pollution restrictions in Idaho make bucket-line dredging unlikely.

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.—Hundreds of feet to 1 mi or more in width, several miles in length, and 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 several million cubic yards of ore and a minimum of 0.5 lb monazite or other radioactive minerals per cubic yard.

Mineralogy:

Ore minerals are monazite, euxinite-polycrase, brannerite, samarskite, xenotime, fergusonite, uranophane, columbite, allanite, ilmenite, magnetite, zircon, garnet, and gold.

Major commodities:

Listed in order of decreasing 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 per cubic yard to more than 30 lbs per cubic yard 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 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 the stream. Heavy minerals at some deposits have been further concentrated by the winnowing action of flowing water, which 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 precision proton magnetometer survey may aid in delineating the course of enriched paleochannels within the alluvium.

RESOURCE ASSESSMENT

The potential for radioactive minerals in alluvial deposits in the Challis quadrangle was assessed using the following steps. 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 1–18, pl. 23) that contain significant alluvial deposits were identified as study areas. The resource potential of each study area was then assessed, using the following criteria:

Diagnostic criteria:
1. Alluvium contains monazite or radioactive minerals.
2. Alluvial deposit is large; contains more than 10 million cubic yards.
3. Alluvium is derived from an area that was extensively glaciated.
4. Alluvium is in valleys having a low 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 cubic yard of alluvium.
6. Deposit contains 5 lbs of ilmenite per cubic yard of alluvium.

Criteria 5. and 6. are not truly permissive, as defined by Pratt (1981), but they were placed on our list in order to present additional pertinent information. Minimal mineral content is a primary consideration in assessing the potential of a placer deposit.

Scores of the assessment criteria are shown in table 42. From these semiquantitative scores, areas 1 and 8 were classified as having high potential; areas 2–5, 7, 10–12, and 15 as having moderate potential; and areas 6, 9, 13, 14, and 16–18 as having low potential.

Study area 1 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 41). 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 high potential for radioactive mineral resources. The Big Meadow deposit of Bear Valley in area 8 also has produced notable amounts of radioactive minerals (table 41). 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 area 8 that have not been tested but are geologically favorable include alluvium beneath meadows along Elk Creek and Porter Creek, along Ayers Creek, and along lower reaches of Fir Creek.

A moderate potential is assigned to areas 2 (Garden Valley), 3 (South Fork Salmon River), 4 (Deadwood Valley and upper Johnson Creek Valley), 5 (White Hawk basin), 7 (Sulphur Creek), 10 (Payette placer), 11 (Beaver Creek–Cape Horn Creek locality), 12 (Sawtooth Valley), and 15 (Warm Springs Creek valley). The Gold Creek–Williams 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, such as at the Kelly Creek and Stanley Creek placers (table 41) and along Meadow Creek (Storch and Holt, 1963), did not encounter high-grade material. 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 10 contains the Payette placer, which is along the South Fork 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 cubic yard and 4.02 lb of heavy nonmagnetic material per cubic yard. The heavy nonmagnetic fraction was analyzed and found to have an average content per cubic yard of 0.320 lb Nb_2O_5, 0.0015 lb Ta_2O_5, and 0.0004 lb U_3O_8 (Kiilsgaard and others, 1970).

Area 15 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 0.5–1 mi wide, and it was explored in 1957 under a U.S. Department of Defense Minerals Exploration Administration contract. Twenty holes drilled in the deposit indicated 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 cubic yard of placer material. Analyses of

Table 42. Scores for recognition criteria for radioactive black-sand placer deposits in the Challis 1°×2° quadrangle, Idaho.

[1, widespread presence of criterion; –1, known absence of criterion; 1/2, presence of criterion in part of area; 0, information insufficient to determine presence or absence of criterion. See plate 23 for location of numbered areas]

Map area	Diagnostic criteria					Total	Permissive criteria						Total	Resource potential
	Contains radio-active minerals	Large size	Extent of Pleistocene glaciation	Low stream gradient	Underlain by or near granite		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 cubic yard	More than 5 lbs ilmenite per cubic yard		
1	1	1	1	1	1	5	1	1	1	1	1	1	6	High
2	1	1	-1	1	1	3	½	-1	1	1	-1	-1	- ½	Moderate
3	1	1	½	1	1	4½	1	½	½	-1	-1	-1	-1	Moderate
4	1	1	1	½	1	4½	1	1	1	-1	-1	-1	0	Moderate
5	1	-1	1	1	1	3	1	1	-1	-1	1	-1	0	Moderate
6	1	-1	1	-1	1	1	1	½	-1	-1	0	0	- ½	Low
7	0	1	1	½	1	3½	½	0	½	-1	0	0	0	Moderate
8	1	1	1	1	1	5	1	1	1	-1	1	1	4	High
9	1	-1	1	-1	1	1	½	½	0	-1	0	0	0	Low
10	1	1	½	½	1	4	½	1	½	-1	-1	-1	-1	Moderate
11	0	1	1	½	1	3½	½	1	½	-1	0	0	1	Moderate
12	½	1	1	1	1	4½	½	1	½	-1	0	-1	0	Moderate
13	0	-1	½	-1	½	-1	½	½	0	-1	0	0	0	Low
14	0	-1	½	-1	1	- ½	½	-1	½	-1	0	0	-1	Low
15	1	1	½	½	½	3½	½	1	1	-1	-1	-1	- ½	Moderate
16	0	½	½	-1	½	½	0	0	0	-1	0	0	-1	Low
17	0	1	½	½	-1	1	0	0	1	-1	0	0	0	Low
18	0	1	-1	-1	-1	-2	½	-1	½	-1	0	0	-1	Low

the heavy-mineral concentrate indicated an average per cubic yard of 0.001 lb U_3O_8, 0.004 lb ThO_2, 0.003 lb Nb_2O_5, 0.001 lb Ta_2O_5, and 0.021 lb rare-earth oxides. 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 they 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 19, 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.

ROCK PRODUCTS

By Frederick S. Fisher and S. Warren Hobbs

Economic value 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 economic value in the foreseeable future.

Sand and gravel are abundant 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 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. 4). 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 Salmon River with the main Salmon River (fig. 4). On Squaw Creek about 1 mi upstream from the Red Bird mine (pl. 1), 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 commercial 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, which 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 batholith and Casto pluton 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 commonly deeply weathered, there being 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.

POSTULATED ORE DEPOSIT TYPES

OPALITE-TYPE MERCURY VEINS

By Theresa M. Cookro and Benjamin 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) described the deposit as being in a downwarped part of the crest of an anticline in strata of the Tertiary (Miocene) Payette Formation. 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).

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 has a macroscopically visible crystal form. Cinnabar is irregularly distributed, filling cracks and coating surfaces. Gold values of 0.01 oz per ton were determined for cinnabar-enriched areas, but the gold is believed to be associated with pyrite. Quartz, feldspar, mica, zircon, and tourmaline were found as sandstone remnants in the deposit.

The ore is within Miocene sandstone that is interbedded with some tuffaceous and shaly rocks. The opalized veins both are concordant to and cross cut bedding; some follow fracture zones. Steep fractures contain high-grade cinnabar veinlets. 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 that contains subordinate impermeable beds of clayey and sandy shale and some fine-grained clayey sandstone. The sandstone grains are well sorted, moderately coarse, rounded to subangular, and 3–4 mm in diameter. 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. The Columbia River Basalt Group 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 its deposition.

Factors that appear to be critical in the Weiser-type opalite mercury deposits are (1) presence of a massive, originally porous sandstone (Tertiary) that could be flooded with quartz-carrying cinnabar; (2) presence of an impermeable cap, such as a shale bed; (3) presence of a structural trap; and (4) presence of the steep faults.

In the Challis quadrangle, mercury has been produced from the Yellow Pine area and is reported to be present in Garden Valley and along Stanley Creek. At Yellow Pine, cinnabar occurs with chalcedonic quartz at the Hermes mine. Unpublished U.S. Department of Defense Minerals Exploration Administration reports (1953) described cinnabar in veins along the west side of Garden Valley. Choate (1962) reported cinnabar in float and in placer deposits along Stanley Creek.

Miocene sedimentary rocks are known to occur in the Garden Valley area; they are similar, but not identical, to those at Weiser. Large structural traps are not known to be present, but impermeable rocks, either shale or lava, could have acted as caps for fluid circulation in those sediments. Sandstone is 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 be 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 and Spokane Mountain deposits, 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 was described in several papers by Nash and coworkers (Nash, 1975; Nash and Lehrman, 1975; Nash, 1977). A nearby deposit 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 foliation, 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 Proterozoic 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 granitic intrusions and Eocene volcanic rocks, 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 (Robbins, 1978). The ore bodies generally have a tabular form, with bottoms following geometry of the underlying pluton. The greatest thicknesses of ore are found above depressions in the contact with the granitic rocks.

Nash (1977) and Robbins (1978) speculated that these deposits may result from a combination of syngenetic and hydrothermal processes. In addition, remobilization and supergene enrichment may have taken place from Cretaceous time to the present. Uranium-thorium-lead isotopic dating of zircon from the granitic rocks in the Midnight mine indicates an age of about 75 m.y. (Ludwig and others, 1981). Lead-uranium ages of high-grade ores from the same mine are about 51 m.y. Ludwig and others (1981) suggested that at 51 m.y. heated meteoric water enriched and redistributed preexisting low-grade protore. They believe that the protore was formed in the Precambrian country rocks during hydrothermal activity associated with emplacement of the quartz monzonite at 75 m.y.

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 having good permeability and carbonaceous, pyritic, or ferromagnesian compositions. The uranium could have either a plutonic or a volcanic source. The permeability may be either primary or secondary. Composition of the host rock 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) reported higher uranium, thorium, and potassium in the Tertiary intrusions than in the Cretaceous intrusions. Kiilsgaard and others (1970) found high uranium concentrations in stream-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 are along contacts between Tertiary plutonic rocks and Precambrian and Paleozoic sedimentary and metasedimentary rocks.

Although these deposits have some characteristics in common with deposits described earlier as stratiform uranium deposits in sedimentary rocks (see Johnson and Cookro, this volume, p. 167), we believe they are sufficiently different to merit separate treatment in this report. Major differences include (1) old metamorphosed sedimentary rocks as hosts in the Midnite and Spokane Mountain deposits, contrasted with young unmetamorphosed sediments as hosts in the Challis and Stanley areas; (2) metasedimentary host rocks intruded by younger granite in the eastern Washington deposits, contrasted with arkose shed off the granite as hosts in the Challis and Stanley deposits; and (3) uranium concentration strongly influenced by the distribution of carbonaceous debris in the Challis and Stanley deposits, no comparable feature being described for the Midnite and Spokane Mountain deposits. These contrasts suggest the possibility of differences in mineralizing processes, in recognition criteria, and perhaps ultimately in exploration strategies.

VEIN AND REPLACEMENT ALUNITE DEPOSITS

By Kathleen M. Johnson

Vein and replacement alunite deposits are found in volcanic terranes throughout the Western United States and elsewhere in the world. In the United States these terranes are of Tertiary age, as are the alunite deposits; terranes and deposits elsewhere are of various ages. Both the veins and the replacement deposits resulted 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, whereas 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, low-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 hydrothermal cells around the margins of a known Tertiary intrusion. The cores of these altered cells are alunite, whereas 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 intrusion was involved only as a heat source. The location and size of the hydrothermal 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- and base-metal-bearing Amethyst vein. Smith (1981) estimated 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 near and below the base of the sandstone of Monkeymeyer (an informal miner's term), and silver minerals occur 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 were only slightly silicified.

Acanthite is the predominant silver mineral. Most of the ore minerals are 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 sandstone of Monkeymeyer.

In the Challis quadrangle, the Thunder Mountain cauldron complex, the Twin Peaks caldera, 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 that 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 for 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 g Au/ton and have a high ratio of gold to silver; (3) there is commonly 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 being the most abundant (100–1,000 ppm) and 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. Four areas have comparable geologic settings:

(1) Squaw Creek and Kinnikinic Creek (fig. 4), 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. 5), where the Grand Prize Formation is 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 Proterozoic 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).

(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, 1991). Factors pertinent to the possible occurrence of carbonate-replacement gold deposits are the presence of thrust and steep faults that cut the impure carbonate rocks and the presence of extensive jasperoid replacement of parts of the carbonate-bearing strata. No evidence of 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.

Although no deposits have been recognized, we believe the areas described above are the most likely places for Carlin-type replacement gold deposits in the Challis quadrangle.

STRATABOUND COPPER-SILVER DEPOSITS IN PROTEROZOIC QUARTZITES

By Earl H.Bennett[11]

There are numerous occurrences of stratabound copper-silver mineralization in rocks of the Belt Supergroup of Proterozoic age in northern Idaho and western Montana. Many of these are in the Revett Formation of the Ravalli Group. Best known of the Revett-stratabound deposits is at the Troy mine, which began production in 1982 and produces more than 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 were described by Hayes (1984) and Dayton (1983).

Proterozoic 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 Formation. Ruppel (1975) suggested that the Hoodoo was equivalent to the Big Creek Formation in his Lemhi Group. Ekren (1988) questioned the validity of the Hoodoo Quartzite, which he suggested may be part of the Yellowjacket Formation. Bennett (1977) and Lund and others (1983) suggested that outcrops of white quartzite that were mapped as Hoodoo or Big Creek Formation 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 Formation, 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 Proterozoic white quartzite in the Challis quadrangle is very low.

[11]Idaho Geological Survey.

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APPENDIX.
DESCRIPTION OF MAP UNITS AND TABLES TO ACCOMPANY MISCELLANEOUS INVESTIGATIONS SERIES MAP I–1819, GEOLOGIC MAP OF THE CHALLIS 1°×2° QUADRANGLE, IDAHO

Compiled by

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This text is reprinted from the separately published map, including the original page numbers at the bottom.

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TABLES

EXPLANATION OF FORMAT

In this pamphlet, descriptions of rock units are arranged in the traditional manner (youngest to oldest) except for rocks of Tertiary age. Because of the large number of Tertiary units, the descriptions and correlation table (see map sheet) have been divided into seven sections on the basis of similarities in volcanotectonic history (see "Areal index to subdivisions of Tertiary rocks," on map sheet). Rock units that are present in more than one area are fully described for the area in which they are best known. Cross references between areas are provided. Within each area, the rocks are subdivided into intrusive and extrusive groups and described from youngest to oldest. An index to map units follows the list of references (p. 32).

Modal analyses are reported in abbreviated form: phenocryst abundance is reported as volume percent of rock sample ("phenocrysts (30)" means that 30 percent of the rock consists of phenocrysts); phenocryst mineral abundance is reported as percent of total phenocrysts. Names of minerals are abbreviated: q, quartz; af, alkali feldspar; pf, plagioclase feldspar; b, biotite; hb, hornblende; px, pyroxene; cpx, clinopyroxene; opx, orthopyroxene; ol, olivine; op, opaque oxides.

Wherever it was necessary to use place names in the description of map units, we have provided geographic coordinates to the nearest minute, shown with latitude first and longitude following. These should enable the reader to locate the feature, map unit, or structure in question. In many cases the named location does not appear on the base map due to lack of space. Such locations are, generally, named on topographic quadrangles of larger scale.

A number of dating methods have been used in the Challis quadrangle. Potassium-argon and ^{40}Ar–^{39}Ar ages are listed in tables 1, 2, and 3 and cited where appropriate in the description of map units. The correlation of Tertiary units shows our best estimates of the ages of Tertiary rocks; these estimates are based on stratigraphic relations, selected radiometric ages, and limited magnetic polarity data. Where the radiometric age falls outside the time span shown on the correlation, it is our opinion that other data are more compelling than the radiometric age.

DESCRIPTION OF MAP UNITS

QUATERNARY SURFICIAL DEPOSITS

Qd **Quaternary deposits, undivided (Holocene and Pleistocene)**—Includes modern stream alluvium, terrace gravel, talus and related slope material, landslide debris, and unconsolidated glacial moraines and outwash gravel

Qa **Alluvium, undivided (Holocene)**—Floodplain, terrace, and alluvial-fan deposits that include stream-deposited gravel, sand, and silt. Gravel and peat are in filled ponds and lakes

Qf **Alluvial-fan deposits (Holocene)**—Shown separately only in area near Challis and Antelope Flat (44°18′ N., 114°04′ W.), 30 km north of southeast corner of quadrangle

Ql **Landslide and related deposits (Holocene)**

Qm **Glacial deposits, undivided (Pleistocene)**—Unsorted boulders, cobbles, pebbles, sand, silt, and clay in moraines and in glaciofluvial outwash. Belt of coalescent moraines along eastern front of Sawtooth Range has been attributed to two major late Pleistocene glaciations, the Bull Lake and the Pinedale (Williams, 1961)

Qtr **Travertine (Pleistocene)**—Yellowish-white to cream-colored, irregularly thin- to medium-bedded, locally finely banded deposits of travertine showing varying degrees of irregular cellular and concentric texture with local cavities and encrustations. Layering in most of the deposit is nearly horizontal. Many exposures at eastern margin have steeply inclined layering; some of these clearly are of slumped blocks; others could be of undisturbed travertine deposited on steep slopes. Thought to once have covered about 2.5 km^2 on southwest side of Bradbury Flat (44°26′ N., 114°10′ W.). Probably related to presently extinct hot springs that issued from faults in underlying Paleozoic carbonate strata. Estimated thickness 100 m

MIOCENE VOLCANIC AND SEDIMENTARY ROCKS

Tcb **Columbia River Basalt Group (Miocene)**—Dark-gray to black, fine-grained ophitic basalt; consists chiefly of plagioclase laths embedded in augite, and scattered crystals of magnetite. Exposures include small cap on ridge immediately west of Grimes Pass (44°01′ N., 115°49.8′ W.) and small outcrops west of Paddy Flat (44°45′ N., 115°59′ W.), near northwest corner of quadrangle

Tpa **Payette Formation (Miocene)**—Stratified, tan to gray, loosely consolidated arkosic sandstone and siltstone and interstratified conglomerate and thin-bedded, dark-gray to black shale in which are abundant impressions of upper middle to lower upper Miocene leaves (W. C. Rember, written commun., 1983). Formation also contains seams of low-rank coal as much as 30 cm thick, bedded intervals several meters thick of light-gray to white diatomaceous earth, and beds of gray volcanic ash as much as 30 cm thick. Formation crops out along west side of Middle Fork of Payette River northwest of Crouch (44°07′ N., 115°58′ W.). It was deposited in an intermontane basin and is now part of a west-tilted, down-faulted block. Minimum thickness 1,680 m; base not exposed

EOCENE CHALLIS VOLCANIC GROUP; SEDIMENTARY AND IGNEOUS ROCKS

The Challis Volcanic Group is here raised in stratigraphic rank to replace the formation name "Challis Volcanics" (Ross, 1937) in this map area. The Challis Volcanic Group contains a large number of informal map units, many of which may be defined as formations in the future. The latite-andesite member and the Germer Tuffaceous Member of Ross (1937) are herein abandoned because these terms have fallen into disuse and they do not adequately describe the stratigraphic relations as currently understood. The term "Yankee Fork Rhyolite Member" was abandoned by Foster in 1982.

Thunder Mountain cauldron complex and environs

Intrusive rocks

Trd **Rhyolite dikes**—These small rhyolite intrusions have potassium-argon ages of 39.8±0.9, 41.1±0.9, 42.4±1.5, and 45.2±1.5 m.y. (see table 1). For description, see p. 19

Tqp **Quartz porphyry intrusions**—For description, see p. 4

Tr **Rhyolite intrusions**—Sanidine from a sample taken from Monumental Creek (44°56′ N., 115°12′ W.) was dated by potassium-argon methods at 44.6±1.5 (see table 1). For description, see p. 4

Tmi **Mafic intrusions**—For description, see p. 5

Granitic rocks of Casto pluton

Tg **Granite**—For description, see p. 5

Thg **Hornblende granite**—For description, see p. 5

Tgp **Gray porphyry**—Gray dacite porphyry and minor diorite porphyry. Consists of both extrusive and intrusive rock. These rocks mostly have a dense or cryptocrystalline groundmass but, locally, have a holocrystalline, fine-grained groundmass (diorite porphyry). Phenocrysts of plagioclase generally are conspicuous and, in Indian Creek area (44°48′ N., 115°13′ W.), commonly are 2–3 mm long. Quartz is sparse. Mafic minerals consist of varying proportions of biotite, hornblende, and pyroxene. Phenocryst content varies from about 20 to 50 percent. In places, dacitic rocks clearly intrude lapilli tuff (Tdq) and possibly younger tuff units as well. In other places, rocks appear to be stratiform, having flow layering that defines gentle dips and containing interlayered zones of flow breccia characteristic of contact zones between lava flows. As mapped, therefore, this unit in some places includes dacite lava that is correlative with the lower latite lava (Tll) and in other places includes dikes and irregularly shaped intrusives that probably are younger than lapilli tuff (Tdq). Also correlates in part with dacite and diorite porphyry (Tdc) mapped in western part of quadrangle (see p. 20). For additional description, see p. 5 and 10

Extrusive and sedimentary rocks

Tla **Latite of Lookout Mountain**—Black, nearly aphyric, vesicular lava interbedded with cinders and bombs. Rock locally contains sparse small (0.5 mm long) phenocrysts of plagioclase and small prisms (as long as 1.0 mm) of hypersthene set in groundmass of randomly oriented plagioclase microlites and glass. Leonard and Marvin (1982) report whole-rock potassium-argon ages of 41.0±1.4 m.y. and 43.4±1.4 m.y. for two samples collected just north of Challis quadrangle. Thickness 0–50 m

Tds **Beds of Dewey mine**—Cauldron-filling sedimentary rocks and bedded, reworked ash-fall tuff. Includes siltstone in varved lake beds and coarse volcaniclastic conglomerate containing intercalated landslide debris and talus; carbonaceous in part. Thickness 0–50 m

Tss **Sunnyside tuff of Shannon and Reynolds (1975)**—An informal term used by Shannon and Reynolds (1975) in the Thunder Mountain mining district and now used throughout the Thunder Mountain cauldron complex.

Potassium-argon ages of biotite from one sample and sanidine from two samples are 47.7±1.6, 46.3±1.1, and 46.3±1.0 m.y. (see table 1)

Tsu **Upper tuff**—Red- and red-brown-weathering, densely welded, devitrified rhyolite tuff; multiple-flow compound cooling unit that contains numerous small volcanic rock fragments and well-flattened pumice lapilli throughout. Base is marked by a black vitrophyre 3–10 m thick that is rich in lithic fragments. Extremely sparse biotite flakes are only visible mafic minerals in devitrified rock; pyroxene and hornblende are only visible mafic minerals in vitrophyre. Phenocrysts (12–31): q, 20–60; af, 40–80; b, 0–1; hb, trace (as many as four grains per thin section in basal vitrophyre only); cpx, trace (as many as eight grains pigeonite per thin section in basal vitrophyre only). Allanite is common accessory in basal vitrophyre only. Thickness 0–300 m

Tmx **Megabreccia**—Varicolored breccia consisting of fragments of lower tuff (Tsl, see below), a few centimeters to several meters in diameter, in a matrix of upper tuff (Tsu). The fragments probably slid into caldera from outer rims during initial eruptions of upper tuff. Possibly, rock is a coarse-fragment, lithic-rich, early cooling unit of upper tuff. Thickness 0–100 m

Tslu **Uppermost tuff that has mineralogy of lower tuff**—Reddish-gray, simple cooling unit of densely welded rhyolite tuff. Distinguished from upper tuff (Tsu) by more abundant plagioclase and biotite; separated from upper tuff by few meters of bedded tuff (not shown on map). These rocks are mineralogically similar to lower tuff (Tsl) but are separated from it by rhyolitic lava (Tsrl). Phenocrysts (26): q, 40; af, 44; pf, 12; b, 3; altered mafic, 1. Thickness 0–40 m

Tsrl **Rhyolite lava or tuff**—Red flow-layered lava or extremely hot ash-flow tuff; presence of several zones of black vitrophyre within rhyolite suggests presence of two or more cooling units; east of Marble Creek (44°50′ N., 114°59′ W.) a thin flow of black vesicular latite is intercalated within unit. Although rock in all places looks very similar, containing 5–10 percent phenocrysts (0.5–5 mm in length), rock east of Marble Creek contains more plagioclase than alkali feldspar, and rock exposed north of Dynamite Creek (44°53′ N., 114°05′ W.) contains more alkali feldspar than plagioclase. Thickness 0 to more than 100 m

Tsl **Lower tuff**—At least three cooling units, each of which grades upward from white to pink, nonwelded to slightly welded rhyolite at base to gray, densely welded quartz latite at top. Upper and middle cooling units commonly display vertical sheeting or jointing and contain very little recognizable pumice, whereas lower unit contains abundant pumice. Upper unit along Marble Creek (44°50′ N., 114°59′ W.) contains 28–49 percent phenocrysts: q, 9–45; af, 32–51; pf, 16–33; b, 2–11; hb, 0–3; zircon, trace. Middle unit along Little Cottonwood Creek (44°55′ N., 115°03′ W.) contains 15–34 percent phenocrysts: q, 26–51; af, 23–39; pf, 2–26; b, 4–13; hb, trace. Quartz latite upper part of this cooling unit contains sanidine phenocrysts as long as 8 mm. Lower cooling unit, same location, contains 18–28 percent phenocrysts: q, 6–51; af, 11–38; pf, 12–62; b, 9–21 (in books); zircon, trace. Phenocrysts in lower parts of all three cooling units rarely exceed 2 mm in length. Cauldron-wide hydrothermal alteration (mostly propylitization) has led to albitic replacement of sanidine. Thickness 0–500 m

Tbr **Buff rhyolite**—Buff rhyolite, in contrast to lapilli tuff (Tdq, see below), is nearly aphyric, containing only about 1 percent phenocrysts consisting of plagioclase (0.5–1.5 mm in length), traces of biotite, and an altered prismatic mafic mineral. Rhyolite is flow laminated and layered; either it is an unusually widespread lava or it originated as an extremely hot ash-flow tuff that has not retained any identifiable fragmental or pyroclastic textures. Mapped in northwestern part of cauldron complex, where it presumably occupies same stratigraphic position as lapilli tuff. Thickness 0 to more than 300 m

Tpl **Perlitic rhyolite**—Three rhyolite cooling units separated by green epiclastic sediments. All units have black vitrophyre at base and grade upward to devitrified, lavender to salmon, flow-layered lava or high-temperature, densely welded tuff. Upper cooling unit is ash-flow tuff having nonwelded top. Upper unit vitrophyre in headwaters of Rush Creek (44°56.5′ N., 115°00′ W.) contains 14 percent phenocrysts: pf, 82; af, 11; hb, 7; cpx, trace. Lower unit, same location, contains

3–5 percent phenocrysts: pf, 31–76; af, 24–69; hb, 0–2; cpx, trace. Phenocrysts rarely exceed 2 mm in length. Thickness 0 to more than 300 m

Tdq **Dime- and quarter-size lapilli tuff**—A complex sequence of ash-flow tuff, commonly separated by beds of tuffaceous sandstone and siltstone, and locally by thin black latite lava. Eruption of these tuff units caused initial collapse of Thunder Mountain cauldron complex. They are Thunder Mountain analog of tuffs of Camas Creek-Black Mountain (Tc, see p. 6) in Van Horn Peak cauldron complex. Most are densely welded and contain collapsed pumice lapilli that in plan view are about the size of dimes and quarters; locally larger. Lapilli are mostly dark green or brownish green and contrast with lighter colored green-gray or buff matrix. Tuffs are pervasively propylitized and mafic minerals are altered to chlorite, calcite, and iron oxide. In contrast to overlying tuff (Tsl), lapilli tuff (Tdq) is chiefly pyroxene-bearing. In a specimen from Indian Creek (44°50′ N., 115°15′ W.), pyroxene is principally clinopyroxene. Phenocrysts generally less abundant and smaller than those in lower tuff of Sunnyside (Tsl), and most tuffs are quartz poor. Phenocrysts (9–16): q, trace–5; af, 2–8; pf, 70–83; b, trace–2; hb, 0–4; cpx (mostly altered), trace–16. Some crystal-poor, quartz-free, flow-layered tuffs near head of Prospect Creek (44°48′ N., 114°55′ W.), east of Marble Creek, contain more alkali feldspar than plagioclase. Similar tuffs occur west of Shellrock Peak (44°57′ N., 114°57′ W.) just below perlitic rhyolite (Tpl). Thickness 0 to more than 500 m

Tdql **Lower densely welded tuff**—Quartz-rich, gray tuff within lower latite lava (Tll, see below) that closely resembles lower tuff of Sunnyside (Tsl). Phenocrysts (23–30): q, 27–35; af, 20-26; pf, 34–38; b, 1–3; hb, trace–1; altered mafic mineral, 2–11. Thickness 0 to more than 30 m

Tll **Lower latite lava**—Mostly dark-gray and dark-purplish-gray, flow-layered lava consisting both of crystal-poor flows that probably are about same composition as much younger latite of Lookout Mountain (Tla) and conspicuously porphyritic flows that probably are dacite or rhyodacite in composition. Porphyritic flows contain 30–40 percent phenocrysts of plagioclase as long as 6 mm and abundant mafic minerals, consisting of varying proportions of biotite, hornblende, and pyroxene. Potassium-argon ages reported by Leonard and Marvin (1982) suggest an age range of 48–50 m.y. for this sequence—virtually the same as reported for older intermediate lava (Tdf) exposed farther east and southeast (McIntyre and others, 1982). Sanidine yielded an age of 50.8±1.7 m.y. (see table 1). Thickness 0 to more than 500 m

Tcv **Challis Volcanic Group, undivided**—Thickness 0 to more than 50 m

Northern part of Van Horn Peak cauldron complex and Panther Creek graben

Intrusive rocks

Tqp **Quartz porphyry intrusions**—Dikes and plugs of pink porphyry that varies greatly in size of phenocrysts and texture of groundmass; typically contains smoky quartz phenocrysts as much as 3–4 mm long, tabular alkali feldspar and sparse plagioclase phenocrysts as much as 6–8 mm long, and sparse flakes and books of biotite as much as 3 mm long, in dense micrographic groundmass of quartz and alkali feldspar; commonly, however, has microgranular or cryptocrystalline groundmass. Locally contains extremely large phenocrysts of resorbed quartz in bipyramids as much as 1 cm long and alkali feldspar and plagioclase phenocrysts as much as 3 cm long in graphic groundmass. Single large sanidine crystal 3 cm long from dike east of Yellowjacket Creek (44°59′ N., 114°24′ W.) yielded a potassium-argon age of 44.4±1.0 m.y. (see table 1). The quartz porphyry is described as pink granophyre by Ross (1934). Some dikes contain rhyolite without quartz phenocrysts; in places these quartz-poor dikes were included with lapilli tuff (Tdq), in other places with rhyolite intrusions (Tr, see below). Phenocrysts (19–35): q, 15–58; af, 37–83; pf, 0–12; b, trace–4

Tr **Rhyolite intrusions**—Dikes and plugs of mostly light-gray, dense, phenocryst-poor rhyolite; locally contains conspicuous phenocrysts of sanidine as long as 8 mm and sparse phenocrysts of quartz, as at Red Rock Peak, along northern border of Challis quadrangle at long 114°25°30′ W. Rock at Red Rock Peak grades into, and forms composite bodies with, quartz porphyry intrusions (Tqp). Sanidine from Red Rock Peak yielded potassium-argon age of 44.6±1.5 m.y. (see table 1)

Tmi **Mafic intrusions**—Dikes and plugs of basaltic composition similar to or same as basaltic lava (Tb, see below). Includes mafic to intermediate rocks, near Van Horn Peak and elsewhere, that are conspicuously porphyritic, containing phenocrysts of pyroxene (hypersthene, pigeonite, or both) and plagioclase as long as 5 mm; locally contains sparse biotite and hornblende

Tvp **Tuff of Van Horn Peak**—Vent-filling tuff exposed about 10 km south of Black Mountain consisting of a discontinuous outer rim as much as 50 m wide of light-gray tuff that is virtually identical to basal part of tuffs of Camas Creek-Black Mountain (Tc, see p. 7), and a core, 1 km or more in diameter, of tuff that appears identical to tuff of Table Mountain (Ttm, see p. 7)

Granitic rocks of Casto pluton

Tg **Granite**—Corresponds to "Casto pluton" of Ross (1934) and of Cater and others (1973). Mostly equigranular pink granite: q, 22–34 (0.2–5 mm long); af (perthitic cloudy orthoclase and microcline), 31–57 (0.5–10.0 mm long); pf, 18–33; b, 20–37; hb, 0–3.5; trace amounts of sphene and allanite. These rocks plot in granite field of both Johannsen (1948) and Streckeisen (1973). Also includes light-gray rocks that are distinctly richer in plagioclase and fall in quartz monzonite field of Johannsen (1948). Armstrong (1975) reports potassium-argon age on biotite of 43.9±1.3; Leonard and Marvin (1982) report potassium-argon age from the same locality, also on biotite, of 47.8±1.9 m.y. (see table 1). On Loon Creek (44°43′ N., 114°48′ W.), biotite from the granite has a potassium-argon age of 45.1±1.6 m.y. (see table 1). Biotite from fine-grained, light-gray rock exposed near Grouse Lake (44°50′ N., 114°41′ W.) has a potassium-argon age of 46.6±1.6 m.y. (see table 1)

Thg **Hornblende granite**—Corresponds to hornblende granite of Ross (1934). Mostly buff to pink, medium-grained hornblende granite (Johannsen, 1948); however, one sample from Marble Creek (44°48′ N., 114°58′ W.) and one from Loon Creek (44°44′ N., 114°49′ W.) are quartz syenite (Streckeisen, 1973). A sample from just south of Woodtick Summit (44°47′ N., 114°41′ W.) contained less quartz and alkali feldspar and is quartz monzonite according to both classifications. Rock in all three places tends to weather rusty. Composition of samples from Woodtick Summit area, Loon Creek, and Marble Creek, respectively: q, 8.3, 9.3, 13.4; af (mostly cloudy orthoclase), 39.7, 54.9, 57.4; pf, 36.7, 20.1, 12.1; b, 2.2, 0.6, 1.3; hb, 13.1, 12.5, 15.1. Loon Creek and Marble Creek samples each contained several grains of allanite

Tgp **Gray porphyry**—A mixed sequence of gray and green-gray extrusive and intrusive rocks of intermediate composition; most are dacite porphyry that locally displays flow layering, flow brecciation, and dense to glassy groundmass indicating they are lavas. In places, porphyry is massive, has crystalline groundmass, and locally exhibits intrusive contacts with country rock as young as basal part of tuffs of Camas Creek-Black Mountain (Tc, see p. 7). Therefore, this unit, as mapped, probably includes intermediate lava as old as 51 m.y. and younger dikes and irregularly shaped intrusive masses 48 m.y. old or younger. Phenocrysts (30–45): q, 0 (in most rocks) to 5; af, 0; pf, 60–75; b, 1–12; hb, trace–25; px (mostly altered but in places includes both fresh opx and cpx), trace–20. Contacts are gradational over short distances from hornblende- and biotite-rich varieties to pyroxene-rich varieties. Thickness 0 to more than 500 m. For additional description, see p. 2 and 10

Tdi **Dikes and plugs of intermediate composition**—Not shown separately in this area. For description, see p. 10

Extrusive and sedimentary rocks

Toc **Colluvium of Panther Creek**—Poorly consolidated sandstone, mudstone, boulder conglomerate, and tephra; locally carbonaceous; includes large landslide masses of diverse volcanic rocks. Deposited during subsidence of Panther Creek graben after extrusion of younger part of monolith-forming tuff (Tmt). Some subsidence of graben may have been due to magma withdrawal, but most was probably due to regional rifting concurrent with volcanism. This incompetent sequence of rocks is easily eroded, and landslides are common

Tuff of Castle Rock and related rocks—These rocks are intercalated in Panther Creek graben. The monolith-forming tuff (Tmt), tuff of Castle Rock (Tck), and quartz-biotite tuff (Tqb) were erupted from Castle Rock cauldron segment. Flow-layered rhyolite (Tfl) and basaltic lava (Tb) were derived from unknown sources outside Castle Rock cauldron segment. Strata preserved within Castle Rock half-moon, or trapdoor, cauldron are mostly densely welded. Outside cauldron the only densely welded cooling unit forms cliffs and is mapped as tuff of Castle Rock (Tck)

Tmt **Monolith-forming tuff**—Varicolored, nonwelded to partly welded ash-flow and ash-fall rhyolite tuff. Sequence overlies and underlies a single genetically related, densely welded cooling unit of tuff of Castle Rock (Tck) having identical phenocryst mineralogy. Lower part of monolith-forming tuff locally includes unrelated soft, bedded tuff containing abundant biotite; includes several zones rich in small, variegated volcanic lithic fragments. Rock above and below tuff of Castle Rock (Tck) weathers to tepee-shaped hoodoos and other variously shaped monoliths. Unit typically contains vitric, silky pumice lapilli and fresh black glass shards, but zeolitized and otherwise altered in many places. Phenocrysts (15–25): q, 33-50; af, 50–60; pf, 0–3; b, 0–1; hb, 0-trace; px (mostly pseudomorphs), 0–3; commonly contains smoky quartz and chatoyant alkali feldspar. Thickness 0–300 m

Tck **Tuff of Castle Rock**—Within cauldron includes five cooling units of reddish ash-flow tuff and thin interbeds of ash-fall tuff. Upper cooling unit is densely welded and about 228 m thick. Beneath upper unit are, successively, two thin, partly welded, lithic-rich cooling units, each about 30 m thick; a cliff-forming, moderately welded cooling unit about 150 m thick; and a lowermost slope-forming, partly welded cooling unit rich in lithic fragments, about 190 m thick. Densely welded upper unit is inferred to correlate with densely welded part of outflow unit (Tmt). If this is the case, soft tuff preserved above densely welded unit in Panther Creek graben has been stripped away at Castle Rock (44°49′ N., 114°25′ W.). Phenocrysts, upper cliff-former (28): q, 47; af, 50; pf, 0.7; b, 0.3–0.7; altered cpx, 0.7 (base) to 2.9 (top). Phenocrysts in lower cliff-former show considerable variation from base to top: q, 15 (base) to 45 (top); af, 78 (base) to 49 (top); pf, 3.8 (base) to 4.1 (top); b, trace (base) to 1.0 (top); hb, trace; cpx, 3.1 (base) to 1.4 (top). Same minerals are present in thin cooling units between cliff-formers and in thick, moderately welded lower unit. Quartz is slightly smoky throughout sequence, and all units contain zones of chatoyant alkali feldspar. Total thickness 620 m

Tfl **Flow-layered rhyolite**—Probably at least two cooling units of reddish flow-laminated and layered rhyolite lava or remobilized tuff; had a source outside Castle Rock cauldron but is intercalated with tuff of Castle Rock (Tck) within Panther Creek graben. Phenocrysts (8–11): q, 0–3; af, 80–95; pf, 0–5; b, 0–trace; altered px, 2–12

Tb **Basaltic lava**—Black and brownish-gray lava that probably ranges in composition from potassium-rich basalt to trachyandesite or latite; vesicular to dense; contains scattered small (0.5–2 mm long) phenocrysts of pyroxene and plagioclase in pilotaxitic groundmass composed of plagioclase laths, pyroxene, and glass; locally contains small altered olivine phenocrysts and commonly contains xenocrysts of quartz that have reaction rims composed of tiny pyroxene prisms and glass. Unit is intercalated with rocks as young as basal tuff of Castle Rock (Tck) and with rocks as old as tuff of Ellis Creek (Te, see p. 8). Thickness 0–50 m

Tqb **Quartz-biotite tuff**—Light-green-gray and reddish-gray, locally flow-layered, densely welded ash-flow tuff erupted during collapse of Castle Rock cauldron segment (see table 4). Consists of at least two cooling units. Locally, unit in Panther Creek graben is flow laminated and layered from base to top; these characteristics indicate that hot ash flows there coalesced to liquids before coming to rest. Elsewhere, especially on slopes south of West Fork of Camas Creek (44°47′ N., 114°35′ W.), rock is only locally flow layered and displays zones containing abundant brown-green pumice lapilli that are darker than light-gray or light-greenish-gray enclosing matrix. Abundance and relative proportions of phenocrysts vary greatly. Phenocrysts (20–35): q, 19–50; af, 25–45; pf, 15–40; b, 2–20; hb, trace–5; px, trace. Some quartz phenocrysts in this unit show a peculiar tendency to be biaxial, even where they are not obviously strained. They tend to be smoky and nearly everywhere are incipiently to strongly resorbed. Allanite is a common accessory mineral. Thickness 0–300 m

Tap **Alkali feldspar-plagioclase tuff**—Light-greenish gray and reddish-gray tuff, commonly altered to yellow and various pastel shades; flow-layered and laminated, densely welded, locally containing recognizable well-flattened pumice lapilli. Ash flows in this unit coalesced to liquids before they stopped flowing. Named for sparse, but conspicuous, euhedral phenocrysts of water-clear, "plate glass" tabular alkali feldspar crystals as long as 5–6 mm and altered and inconspicuous euhedral plagioclase crystals as long as 5–6 mm. Spherulitic in several localities; unit has an altered perlitic basal vitrophyre. Phenocrysts (6–10): af, 30–40 (locally as much as 50); pf, 45–66; altered mafic mineral (probably pyroxene), 2–8. Unit is intruded by dense rhyolite at Singheiser (44°51′ N., 114°24′ W.) and Rabbit Foot (44°53′ N., 114°20′ W.) mines and is weakly mineralized. Thickness 0–300 m

Tdt **Dirty tuff**—Three thin, vitric cooling units of densely welded ash-flow tuff rich in lithic fragments. Recognized only in Panther Creek graben. Locally flow laminated and devitrified; typically having vitric gray matrices and well-flattened black, glassy pumice fragments as long as 15 cm; locally called "tiger rock." These units are crystal-poor, plagioclase-bearing tuff that most closely resembles some of the crystal-poor plagioclase tuff in dime- and quarter-size lapilli tuff (Tdq) exposed near Shellrock Peak (44°57.5′ N., 114°56′ W.). Thus, these three units presumably are distal ends of very hot ash flows erupted from Thunder Mountain cauldron complex to west, although their counterparts there have not been positively correlated. Phenocrysts (2–9): af, 0–6; pf, 75–98 (0.4–2 mm long, extensively resorbed); b, 0-trace; hb, 0-trace; opx, trace-19. Thickness 0–150 m

Tuffs of Camas Creek–Black Mountain and related rocks

Tc **Tuffs of Camas Creek–Black Mountain**—A cauldron-filling sequence of mostly very densely welded ash-flow tuff consisting of 10 or more separate cooling units that all are characterized by small phenocrysts (about 2 mm long) that in upper part of sequence consist of plagioclase and fairly abundant mafic minerals, in middle part consist of plagioclase and sparse to moderate amounts of alkali feldspar, and in lower part consist of plagioclase and sparse alkali feldspar and quartz. Entire sequence contains abundant mafic minerals consisting mostly of altered pyroxene, and includes variable amounts of biotite and sparse hornblende. Lower part of sequence has more biotite and hornblende than pyroxene. Assemblage is similar to tuff of Eightmile Creek (Tem, see below) although phenocrysts make up a greater proportion of tuff of Eightmile Creek. Phenocrysts in upper cooling unit (11–40): q, 0–trace; af, 0–trace; pf, 67–75; b, trace–13; altered hb, 0–trace; altered pyroxene, 10–20. Phenocrysts in middle cooling unit (5–25): q, 0–trace; af, trace–20; pf, 65–77; altered b, trace–9; altered hb, trace–3; altered px, 3–10. Phenocrysts in lower cooling unit (3–15): q, 2–12; af, 2–8; pf, 60–75; altered b, 2–10; altered hb, trace–3; altered px, trace–10. Sequence appears to have been almost entirely confined to cauldron complex formed principally as result of eruption of tuff of Ellis Creek (Te, see below). Only thin, partly welded ash-flow tuff and minor ash-fall tuff appear outside the complex. Outflow units are mapped with tuff of Pennal Gulch (Tp, see below). Thickness 0–3,000 m

Ttm **Tuff of Table Mountain**—Outflow equivalent of tuff of Van Horn Peak. For description, see p. 8

Tcs **Tuffs of Camas Creek–Black Mountain and bedded strata, undivided**—Thin ash-flow-tuff cooling unit of Camas Creek-Black Mountain lithology interbedded with thin-bedded ash-fall tuff of similar lithology and lacustrine tuffaceous siltstone, sandstone, and conglomerate. Thickness 0–100 m

Tp **Tuff of Pennal Gulch**—For description, see p. 13 and 16

Trb **Rhyolite of Red Butte**—For description, see p. 13

Tpq **Quartz-phenocryst perlite**—Pink and orange-gray, flow-laminated, hydrated rhyolite glass that has retained its perlitic texture despite deep weathering and alteration; mapped in all localities to include subjacent and superjacent horizontal beds of tuff and tuffaceous sandstone. Quartz is amethystine to smoky and as much as 4 mm long. Phenocrysts (21–33): q, 27–35; af, 9–31; pf, 19–47; b, 6–12; hb, 4–6.5; altered px, 2. Thickness 0–35 m

Tem **Tuff of Eightmile Creek**—Two or more cooling units of green-gray quartz latitic and rhyodacitic ash-flow tuff that together are more than 300 m thick near Sleeping Deer Mountain (44°46′ N., 114°41′ W.) within cauldron complex, but rarely exceed a few tens of meters each outside cauldron complex or Custer graben. Unit overlies tuff of Ellis Creek (Te), underlies the tuffs of Camas Creek-Black Mountain (Tc), and locally shares some characteristics of each unit. Included in tuff of Pennal Gulch (Tp) south of Table Mountain. Where densely welded and rich in phenocrysts, it is not easily distinguished from tuff of Ellis Creek; it differs only in containing significant amounts of alkali feldspar and fewer mafic minerals. Phenocrysts (14 (weakly welded) to 46 (densely welded within the cauldron complex)): q, 10–22; af, 6–16; pf, 44–63; b, 6–16; hb, 1–5; px, trace–2. Unit contains abundant apatite, modest amounts of zircon, and sparse allanite as accessories. Most quartz phenocrysts are slightly embayed. Large grains that are extensively embayed are common. Biotite from exposures of this unit near West Fork of Morgan Creek (44°43′ N., 114°15′ W.) has potassium-argon age of 48.4±1.7 m.y. (see table 1), which agrees with stratigraphic position of this tuff, below 47.8-m.y.-old tuff of Table Mountain (Ttm). Thickness 0 to more than 300 m. For additional description, see p. 9, 13, and 15

Tl **Potassium-rich andesite, latite, and basalt lava**—For description, see p. 17

Te **Tuff of Ellis Creek**—Rhyodacitic, crystal-rich ash-flow tuff characterized by phenocrysts of plagioclase, strongly resorbed quartz, and abundant biotite and hornblende, all of which are present in subequal amounts. Rocks exposed within cauldron complex commonly are partly altered to chlorite, epidote, and associated minerals. Locally, as along West Fork of Camas Creek (44°49′ N., 114°18′ W.), abundant very fine grained magnetite darkens rock. Sample from northeast of Duck Peak (44°55′ N., 114°29′ W.), in Panther Creek graben, has potassium-argon age on biotite of 48.4±1.6 m.y. (see table 1). Thickness 0 to more than 2,000 m. For additional description, see p. 9 and 13

Tdf **Dacitic and rhyodacitic lava**—Principally cliff-forming, dark-gray, conspicuously porphyritic lava of dacitic composition; blocky weathering; inconspicuous flow layering; unit locally includes phenocryst-poor, dark-purplish-gray latite or andesite. Phenocrysts, dacitic lava (25–40): q, 0–trace; pf, 60–70 (as long as 6 mm); b, 0–4; hb, 15–23; cpx, trace–15; opx, trace. In some areas mafic minerals are oxidized to black opaque iron oxides or replaced by chlorite and iron oxide. Latite or andesite lava contains 5–15 percent phenocrysts (0.5–2 mm long) of plagioclase and clinopyroxene, and traces of orthopyroxene and oxidized hornblende; locally, pyroxene and hornblende phenocrysts are as long as 1 cm. Biotite from sample collected near Red Rock Peak (45°00′ N., 114°25′ W.), in Panther Creek graben, gave potassium-argon age of 48.6±1.7 m.y. (see table 1). Sample from Little West Fork of Morgan Creek (44°42′ N., 114°19′ W.) has potassium-argon age on biotite of 51.1±1.8 m.y. (see table 1). Thickness 0 to more than 1,000 m. For additional description, see p. 14, 15, and 18

Tmz **Intermediate lava and breccia of mixed zone**—This lava crops out east of Morgan Creek Summit (44°47′ N., 114°15′ W.). For description, see p. 9

Tlt **Lithic tuff of Corral Creek**—For description, see p. 9

Tfr **Flow-laminated rhyolite or quartz latite lava**—For description, see p. 9

Corral Creek cauldron segment and area north and east of Challis

Intrusive rocks

Tmi **Mafic intrusions**—For description, see, p. 5

Tinm **Intermediate and mafic intrusions**—Similar to intermediate and mafic lavas (Tl), listed on p. 17. Additional description on p. 11

Extrusive rocks

Tcr **Tuff of Challis Creek, outflow unit**—For description, see p. 12 and 16

Ttm **Tuff of Table Mountain**—Pale-grayish-red to yellowish-brown, densely welded rhyolite or quartz latite ash-flow tuff; probably a simple cooling unit. Phenocrysts (10–13): pf, 82–90; b, 7–13; altered px, 2–5. Black basal vitrophyre a few meters thick contains abundant small volcanic lithic fragments a few millimeters to a few centimeters in diameter. Biotite from vitrophyre has a potassium-argon age of 47.8±1.7 m.y. (see table 1). Unit has reversed magnetic polarity. Source for this unit is a vent at Van Horn Peak (44°46.5′ N., 114°19.5′ W.) (Ekren, 1981). Thickness 0 to more than 100 m

Tp **Tuff of Pennal Gulch**—For description, see p. 13 and 16

Tem **Tuff of Eightmile Creek**—Light-gray and green-gray, massive-weathering, partly welded and densely welded quartz latite or rhyodacite ash-flow tuff; appears to be simple cooling unit in Corral Creek area (44°45′ N., 114°14′ W.), where it is poorly exposed and, in most areas, was not mapped separately at base of tuff of Pennal Gulch (Tp). Phenocrysts (25–35): q, 13-19; af, 12–18; pf, 47–57; b, 9–14; hb, trace–2; cpx, trace. Thickness 0–50 m. For additional description, see p. 8, 13, and 15

Tl **Potassium-rich andesite, latite, and basalt lava**—In Corral Creek area (44°45′ N., 114°14′ W.), thickness is 0–700 m. For description, see p. 17

Tdm **Tuff of Degan Mountain**—Pink and reddish-gray, densely welded rhyodacite ash-flow tuff; uncommonly rich in mafic minerals; appears to have erupted from west flank of Degan Mountain (44°57′ N., 114°06.5′ W.) where composite vent also contains mafic, nonfragmental intrusive rock (Tinm). Contains numerous small quartz phenocrysts about 1 mm long and a few slightly larger quartz xenocrysts that have reaction rims of tiny pyroxene microlites and glass. Phenocrysts (20–32): q (includes xenocrysts), 5–15; af, 4–18; pf, 29–58; b, 2–8; hb, 14–36; cpx, 6–26; opx, trace. Thickness 0–50 m

Te **Tuff of Ellis Creek**—Light-green-gray, massive-weathering, densely welded rhyodacite ash-flow tuff that is outflow from Van Horn Peak cauldron complex. A multiple-flow compound cooling unit or, possibly, two cooling units; everywhere contains conspicuous pumice; contains zones within which pumice lapilli are lighter than matrix and zones within which lapilli are darker than matrix. Phenocrysts (36–50): q, 4–15 (commonly "worm-eaten" and as long as 4 mm); pf, 60–75 (as long as 6 mm); b, 12–20; hb, 8–16; cpx, trace. Thickness 0–300 m. For additional description, see p. 8 and 13

Tdf **Dacitic and rhyodacitic lava**—For description, see p. 8, 14, 15, and 18. Thickness 0–900 m

Tmz **Intermediate lava and breccia of mixed zone**—A heterogeneous mixture of mafic and dacitic lava and flow breccia interbedded with tuff breccia, mud flows, and debris flows; locally includes well-stratified boulder and cobble conglomerate containing petrified tree stumps and logs; entire sequence principally forms slopes, but in and adjacent to canyons weathers to hoodoos and monoliths. Matrix of breccia and mud flows is rich in montmorillonite and weathers to spongy texture; slimy when wet. Individual tabular lava flows are mostly latite or andesite that appears to be same composition as lava in younger map unit Tl. Tabular lava flows are dark purplish gray and brownish gray; vesicular. Phenocrysts (5–30): pf, 55–70 (0.5–2 mm long); cpx, 10–20 (mostly less than 3 mm long); opx, 10–20 (mostly less than 2 mm long); hb, trace–5. In hand specimens of some of these mafic lavas, only clinopyroxene (as long as 1 cm) as phenocrysts is visible, whereas in others hornblende (as long as 3 cm) is only apparent phenocryst. Groundmasses are principally pilotaxitic. Dacitic lava and breccia are identical in composition to cliff-forming, conspicuously porphyritic lava (Tdf), but in this unit they consist mostly of slope-forming flow breccia. A porphyritic rhyodacite lava near base contains same phenocryst assemblage as tuff of Ellis Creek (Te). Thickness 0–900 m

Tlt **Lithic tuff of Corral Creek**—Reddish-gray, greenish-gray, and yellowish-gray, densely welded, cliff-forming dacite or rhyodacite ash-flow tuff rich in lithic fragments; possibly comprising two separate multiple-flow cooling units. Phenocrysts (13–38): q, 0–1; pf, 72–85; b, 0–4; hb, 3–5; opx, 7.5–22. Extrusion of this tuff apparently triggered subsidence of Corral Creek segment of Van Horn Peak cauldron complex (see table 4). In places, tuff grades upward into debris flow containing abundant latite and dacite clasts. Thickness 0–200 m

Tfr **Flow-laminated rhyolite or quartz latite lava**—Yellowish-brown, slope-forming, massive-weathering, aphyric rock; in most exposures this rock more closely resembles massive siltstone than volcanic rock. Thin sections contain a crystal or two of albite (2 mm long) and a single flake of biotite in groundmass of dense felt of alkali feldspar microlites

Twin Peaks caldera and southern part of Van Horn Peak cauldron complex

Intrusive rocks

Trf **Rhyolite dikes, plugs, and flows**—Light-gray, tan, and pinkish-red, generally crystal-poor or only moderately crystal-rich, porphyritic intrusive rocks and minor flows. Rock typically contains phenocrysts of quartz and sanidine in variable amounts; plagioclase locally present in minor amounts. Locally contains minor biotite and, rarely, trace amounts of pyroxene. These rocks display fabrics ranging from massive to flow-laminated to autobrecciated. In thin section, textures vary from glassy to devitrified to fine grained, allotriomorphic, and granular. In ridges between East Fork of Mayfield Creek and Yankee Fork (44°30′ N., 114°40′ W.) at least two generations of rhyolite are present. Older rhyolite is glassy to devitrified and is intruded by dikes and pluglike masses of more massive rhyolite. Narrow rhyolite dikes and irregularly shaped intrusive masses pervade west and north margins of Twin Peaks caldera and crosscut lower part of tuff of Challis Creek (Tcrl, see p. 12) and the caldera-wall slump debris (Tsd, see p. 11). Potassium-argon age of sanidine is 46.5±1.7 (see table 1)

Tfd **Felsic dike rocks**—Light-gray to brown-gray, light-brown-weathering dikes of porphyritic trachyte and(or) rhyolite that contain phenocrysts of sanidine, as long as 5 mm, and locally contain minor amounts of pyroxene and biotite. Plagioclase crystals, where present, generally are small, resorbed, and mantled by alkali feldspar. These dike rocks occur principally within Twin Peaks caldera, where they intrude tuff of Challis Creek (Tcrl, see p. 12) and caldera-wall slump debris (Tsd, see p. 11)

Tqp **Quartz porphyry intrusions**—For description, see p. 4

Tpe **Intrusive rocks of Pats Creek–Upper Eddy Creek**—Light-gray to pinkish-red or lavender, red- to lavender-weathering, fissile to flaggy, flow-laminated, and locally autobrecciated intrusive rock along north and east margins of Twin Peaks caldera. Phenocrysts (9–21): af, 0–25; pf (strong oscillatory zoning), 53–69; b, 17–34; hb, 0–5. Locally, near contacts, rock is black and vitrophyric or perlitic, devitrified, and gray-green weathering. Rock has steep to vertical flow foliation and locally has isoclinal flow folds with steep to vertical axial planes of variable strike. Locally, this rock contains cavities lined with chalcedonic quartz. In hand specimen, rock resembles rhyolite of Red Butte (Trb, see p. 13), except that, unlike rhyolite of Red Butte, it generally contains scattered sanidine phenocrysts. Unit is in intrusive contact with tuff of Challis Creek (Tcr) in upper Pats Creek area (44°36′ N., 114°21′ W.) and in upper Eddy Creek above Eddy Basin (44°40′ N., 114°27.5′ W.). A pluglike mass (not shown on map) containing plagioclase, biotite, sanidine, and hornblende phenocrysts is on Spider Creek (44°40.5′ N., 114°26.5′ W.). This rock is light greenish gray, medium brown weathering, and steeply flow foliated; it contains abundant gas cavities lined with rosettes of gypsum and minor calcite

Tdc **Diorite complex**—For description, see p. 20

Tgp **Gray porphyry**—Biotite from sample collected near Casto (44°34′ N., 114°50′ W.) gave potassium-argon age of 48.6±1.4 m.y. (see table 1). Sample collected from probable extrusive rock 8 km north of Casto yielded hornblende age of 46.9±2.8 m.y. and biotite age of 49.5±1.4 m.y. (see table 1). For description, see p. 2 and 5

Tii **Intermediate dikes or flows**—Dark-brown to purple-brown, dark-brown-weathering, porphyritic dikes or flows containing abundant phenocrysts as much as 3 mm in length of plagioclase and pyroxene, less abundant hornblende, and minor biotite. On lower Bear Creek (44°34.5′ N., 114°24′ W.) a probable dike of this unit, which appears to occupy ring-fracture fault of Twin Peaks caldera, contains phenocrysts of sanidine in addition to above minerals. Contacts of this unit near Mosquito Flat Reservoir (44°31′N., 114°26′ W.) are not exposed, and relations with tuff of Challis Creek (Tcr) are uncertain

Tdi **Dikes and plugs of intermediate composition**—Massive to faintly flow-laminated and locally vitrophyric at intrusive margins. Present in area of East Fork of Mayfield

Creek (44°29′ N., 114°37′ W.) and in Custer graben. In upper Tenmile Creek area (44°28′ N., 114°37′ W.), reddish-brown to lavender, porphyritic rhyodacite intrudes tuff of Eightmile Creek (Tem) and is intruded by porphyritic rhyolite (Trf). Phenocrysts (22–25): pf, 54–58; b, 10–15; hb, 23–26; op, 5–7. Potassium-argon age of intrusive mass on upper Tenmile Creek is 46.0±1.7 m.y. (biotite); 48.9±2.9 m.y. (hornblende) (see table 1)

Tip **Intermediate intrusive rocks of Spider Creek–Parker Creek**—Medium- to dark-gray, brownish-gray, gray- to brown-weathering, porphyritic intrusive rock containing abundant phenocrysts of plagioclase as long as 7 mm and less abundant hornblende, pyroxene, and minor biotite in pilotaxitic microcrystalline to devitrified, blotchy matrix. Where fine grained, rock has steep flow foliation of variable strike and in places flow folds have steep axial planes. This rock intrudes tuffs of Camas Creek–Black Mountain (Tc) at head of Parker Creek (44°37′ N., 114°32′ W.). Unit is intruded by rhyolite (Trf)

Tinm **Intermediate and mafic intrusions**—Includes dark-gray to bluish-black, dark-brown-weathering, aphanitic, porphyritic, intermediate intrusive rocks containing 3–5 percent euhedral plagioclase phenocrysts as much as 6 mm long and 1–2 percent altered euhedral pyroxene phenocrysts. Exposed on Challis Creek at mouth of Eddy Creek (44°35′ N. 114°19′ W.) and on Moose Creek (45° 48.5′ N., 114°10′ W.)

Extrusive rocks

Tuff of Challis Creek—Principal ash-flow tuff sequence erupted with collapse of Twin Peaks caldera (see table 4) (Hardyman, 1981). Caldera-wall slump debris (Tsd) and three ash-flow-tuff units (Tcru, Tcrm, Tcrl) are mapped within caldera. A single ash-flow tuff (Tcr) is mapped outside caldera

Tsd **Caldera-wall slump debris (megabreccia**—Heterogeneous deposit of coarse talus and megabreccia (following usage of Lipman, 1976) interfingering and admixed with ash-flow tuff. Deposits of this material are localized along ring-fracture system on southeast margin of Twin Peaks caldera (44°34′ N., 114°23′ W.) and in northern part of caldera, where they extend into caldera from its north and west margins. In lower part of unit are bedded, indurated, coarse conglomeratic sandstone and angular talus deposits, resembling concrete on fresh fracture; these deposits also form thin, lenslike layers and pods throughout the map unit. Megabreccia consists of tuffaceous matrix-supported to block-supported deposits of angular, unsorted pebble- to boulder-size clasts and house-size blocks of ash-flow tuff, intermediate and siliceous lava, epiclastic rock, and abundant fragments of tuff of Challis Creek. Ash-flow tuff matrix of megabreccia is nonwelded and crystal poor; it resembles tuff of Challis Creek except for higher plagioclase content. Phenocrysts (4–20): af, 40–47; q, 37–57; pf, 3–17; b, trace. Thickness more than 400 m

Tcru **Tuff of Challis Creek, upper unit**—Multiple-flow, compound cooling unit of crystal-rich rhyolite ash-flow tuff. Phenocrysts (22–26 in basal nonwelded tuff, 36–44 in remainder of unit): af, 54–69; q, 25–45; pf, 0–3; b, trace; hb, rare; px, 0–4.5. Accessory minerals are zircon, allanite, and trace amounts of apatite. Sanidine phenocrysts, as long as 5 mm, are chatoyant. Quartz phenocrysts commonly are slightly resorbed, bipyramidal, and smoky. Phenocrysts are somewhat smaller and less abundant in basal part of unit than in densely welded tuff. This unit, like middle and lower cooling units (Tcrm and Tcrl), has little or no plagioclase or ferromagnesian minerals. Plagioclase does not generally exceed 0.5 percent of total phenocrysts, biotite is uncommon, and minor pyroxene grains are preserved only in most densely welded tuff. Except locally near base, this unit is medium-gray to brownish-gray, brown-weathering, densely welded, devitrified ash-flow tuff containing pumice lapilli as much as 12 cm long and 3 cm thick (uncommonly as much as 26 cm long and 2 cm thick) and scattered pebble- to cobble-size fragments of gray to lavender, aphyric intermediate to rhyolitic lava. Pumice lapilli are in places medium to rusty brown and darker than matrix or light gray and lighter than matrix. Sanidine has been dated by ^{40}Ar–^{39}Ar methods at 45.5±0.3 m.y. (see table 3). At base, this tuff is light gray to light brown, nonwelded to moderately welded, and glassy and contains more abundant lithic fragments than do rocks exposed above; lithic fragments less than about 8 cm in diameter constitute 4–6 percent of rock and include porphyritic intermediate lava, light-gray, flow-banded rhyolite (in places as much as 1 m long at base of unit), and fragments of ash-flow tuff that has mineralogy of tuff of Challis Creek. The most pumiceous nonwelded to moderately welded basal part of tuff is as much as 60 m thick and is overlain by densely welded tuff at the base of which is a laterally discontinuous vitrophyre as much as 6 m thick. Original top of unit is not exposed. Thickness is more than 700 m

Tcrm **Tuff of Challis Creek, middle unit**—Two, or possibly three, cooling units of light-gray to greenish-gray or brownish-gray, partly to densely welded, pumiceous rhyolite ash-flow tuff that weathers gray, light brown, or lavender. Phenocrysts (as much as 2 mm long) (15–26): af, 43–59; q, 38–57; pf, 0–trace; b, 0–1.5; px, 0–2. Pumice lapilli in upper cooling unit are greenish brown, darker than matrix, and as much as 6 cm, but generally less than 1 cm, long. In lower cooling unit, pumice lapilli are pale greenish gray and lighter than matrix. Sanidine from zeolitized middle unit gives an ^{40}Ar–^{39}Ar age of 45.9±0.2 m.y. (see table 3). Middle unit (Tcrm) typically is in sharp contact with overlying upper unit (Tcru). There are concentrations of lithic fragments near contact. Middle unit locally overlies thin tuffaceous sediments at contact with underlying lower unit (Tcrl). Thickness 22–48 m

Tcrl **Tuff of Challis Creek, lower unit**—Light- to dark-brownish-gray, brownish-gray-weathering, moderately to densely welded, crystal-rich, pumiceous rhyolite ash-flow tuff. Phenocrysts (2–4 mm long) (15–48): af, 50–71; q, 26–47; pf, 0–3 (generally less than 0.5); b, rare; px (preserved only in vitrophyre), 0–2. Variable amounts of pumice and vertical variation in compaction (welding zonation) within this unit, especially in upper part, suggest compound cooling. Unit shows similar alternating variations in crystal and lithic fragment content. Lithic fragments generally are small and scattered but locally are as much as 0.3 m in diameter and constitute as much as 10 percent of rock. They consist principally of flow-banded, aphyric, felsic lava and moderately crystal-rich, quartz- and sanidine-bearing ash-flow tuff that resembles tuff of Challis Creek. Pumice is lighter or darker than matrix depending on degree of welding, and lapilli commonly range from 1 to 6 cm in diameter but can be as much as 15 cm. Vitrophyric zones of this unit locally are as much as 22 m thick. Tuff forms distinct buff to pale-green, treeless or sparsely tree-covered outcrops where altered to zeolites north and west of Twin Peaks (44°36′ N., 114°28′ W.). Sanidine crystals from this unit were dated at 45.8±0.2 m.y. and 46.5±0.1 m.y. (see table 3). Thickness more than 610 m (base not exposed)

Tcr **Tuff of Challis Creek, outflow unit**—Reddish- to gray-brown, partly to densely welded rhyolite ash-flow tuff containing 13–45 percent phenocrysts (as much as 4 mm long): af, 38–70; q, 27–60; pf, 0–3; b, trace; px, 0–3. Comprises rocks outside Twin Peaks caldera that cannot be correlated with certainty with units within caldera. Outflow tuff of Challis Creek, where it caps high mountain peaks north and west of Twin Peaks caldera, consists of single cooling unit at least 200 m thick. Locally, as exposed on uppermost Tenmile Creek (44°29′ N., 114°39′ W.), outflow tuff of Challis Creek grades upward from crystal-rich, moderately welded tuff to very fine grained, crystal-poor ash-fall tuff. Tuff there and in nearby exposures on upper East Fork of Mayfield Creek (44°30′ N., 114°39′ W.) is interpreted to be associated with an early collapse segment of Twin Peaks caldera that is west of west margin of Twin Peaks caldera proper. This early collapse segment is obscured by a mass of intrusive rhyolite (Trf). Sanidine from this unit was dated by ^{40}Ar–^{39}Ar methods at 46.3±0.2 m.y. (see table 3)

Tqb **Quartz-biotite tuff**—For description, see p. 6

Tc **Tuffs of Camas Creek–Black Mountain**—For description, see p. 7

Tmb **Megabreccia of Ibex Creek**—Heterogeneous deposit of cobble- to house-size blocks of volcanic rock. Blocks include highly fractured pyroclastic rocks that resemble tuffs of Camas Creek–Black Mountain (Tc), rocks that may be tuff of Ellis Creek (Te) and tuff of Eightmile Creek (Tem), intermediate porphyritic lava, and blocks of coarse-grained volcaniclastic rock. Indurated matrix consists of smaller fragments of same materials that make up the blocks. Exposed in slope west of lower Ibex Creek (44°34.5′ N., 114°43.5′ W.). Megabreccia is intruded on all sides by rhyolite (Trf) and gray porphyry

(Tgp). Megabreccia is interpreted to represent caldera-wall slump debris shed from west margin of Van Horn Peak cauldron complex after eruption of tuffs of Camas Creek–Black Mountain (Tc). Thickness more than 150 m

Tp **Tuff of Pennal Gulch**—In Darling Creek area (44°38′ N., 114°17′ W.), unit consists of gray-brown to buff to pale-green or red bedded tuff, tuffaceous sediment, nonwelded ash-flow tuff, and pumice flows. Typical pumice-rich ash-flow tuff or pumice flows contain phenocrysts (2 mm in length) (9–14): af, 0–15; q, 0–7; pf, 62–83; b, 12–26; hb, trace. Ash-flow tuff ranges in thickness from 1 to 52 m and is rich in pumice. Noncollapsed pumice fragments in these tuff beds generally are 1–2 cm in maximum diameter and constitute 30–70 percent of rock, so many of these units are pumice flows. Lithic fragments in these tuff beds typically are pebble-size clasts of aphyric felsic lava and intermediate porphyritic lava containing feldspar and biotite phenocrysts. Interbedded with pumice-flow tuff beds are buff to green and lavender, thin-bedded, fine- to medium-grained fluvial tuffaceous sandstone, siltstone, reworked pumice beds, and coarse conglomerate beds that contain debris-flow lenses and siltstone and range from 1 to 35 m thick. Map unit is at least 355 m thick and is unconformably overlain by tuff of Challis Creek (Tcr). Also see description on p. 16

Trb **Rhyolite of Red Butte**—Red, reddish-gray, lavender, pale-brown, or buff, pinkish-tan to reddish-brown-weathering, flow-laminated and layered rhyolite that forms a cap rock on Red Butte (44°39′ N., 114°20.5′ W.), east of Twin Peaks caldera. On ridge between mouth of Pats Creek and Eddy Creek, just north of Challis Creek (44°35′ N., 114°20′ W.), this unit contains basal flow-banded vitrophyre 10 m thick that grades upward into flow-banded rock that displays crude columnar jointing and contains abundant flattened gas cavities (as much as 8 cm long). Vitrophyre locally flow brecciated with blocks up to 0.3 m. To north, in Morgan Creek area (44°40′ N., 114°17′ W.), rhyolite locally displays pyroclastic characteristics and may represent a pyroclastic deposit that flowed after coalescing to liquid. Phenocrysts (2–5 mm in length) (5–16): pf, 76–81; b, 15–17; hb, 0–11; af (with reaction rims of pf), rare. Abundant accessory apatite and zircon. Allanite uncommon. Biotite from a sample collected on east side of Red Butte (44°37′ N., 114°18′ W.) has a potassium-argon age of 46.9±1.6 m.y. (see table 1). Thickness 0–250 m

Tem **Tuff of Eightmile Creek**—Erosional remnant of this tuff on lower Mill Creek (44°32′ N., 114°17′ W.) overlies thin-bedded tuffaceous sandstone, siltstone, and reworked pumice beds that in turn overlie aphanitic intermediate lava (Tl, see p. 12). Tuff is light greenish gray to brownish gray, nonwelded, and only slightly devitrified; it contains pale-green to white pumice lapilli. Phenocrysts (approximately 26): af, 15; q, 22; pf (strong oscillatory zoning), 33; b, 23; hb (green), 7. On southwest side of Corkscrew Mountain (44°32′ N., 114°23′ W.), erosional remnants of tuff of Eightmile Creek are light gray to greenish gray, nonwelded, and pumiceous, containing medium-brownish-gray pumice lapilli that are darker than matrix. Crystals, as much as 2 mm long, commonly are broken. Phenocrysts (42): af, 15; q, 8; pf (strong oscillatory zoning), 64; b, 12; hb, 1. At Red Butte (44°39′ N., 114°20.5′ W.) about 60 m of this tuff underlies rhyolite of Red Butte (Trb). Tuff is nonwelded to partly welded, very pale gray, and rich in pumice. Phenocrysts (as much as 2.5 mm long) (27–33): af, 11–12; q, 17–22; pf (strong oscillatory zoning), 52–55; b, 13–15; hb, 0–2. From upper Spider Creek to upper Parker Creek (44°38′ N., 114°33′ W.), unit is greenish-gray, densely welded, and pumiceous; contains whitish-green pumice lapilli that generally are lighter than matrix. The tuff is altered to calcite and chlorite; sericite, clay minerals, and epidote locally are present. Biotite from sample from West Fork of Morgan Creek (44°42′ N., 114°18′ W.) has potassium-argon age of 48.4±1.7 (see table 1). Phenocrysts (25–35): af, 12–17; q, 9–27; pf, 43–66; b, 7–18; hb, 2–4. For additional description, see p. 8, 9, and 15.

Tl **Potassium-rich andesite, latite, and basalt lava**—For description, see p. 15

Te **Tuff of Ellis Creek**—Along lower Eddy Creek this unit consists of two outflow cooling units, each about 60 m thick, separated by 1–2 m of thin-bedded tuff and reworked, cross-bedded, fluvial tuffaceous sandstone containing abundant biotite. Ash-flow tuff in both cooling units is gray green and moderately welded; contains pale-green pumice lapilli as much as 3 cm long. Phenocrysts (28–34): q, 3–6; pf, 66–67; b, 22–24; hb, 5–6. For description, see p. 8 and 9

Trm **Rhyolite of Mill Creek Summit**—For description, see p. 17

Tsb **Sedimentary breccia**—A heterogeneous unit consisting primarily of poorly sorted, poorly bedded, coarse sedimentary breccia that contains angular to rounded, pebble- to boulder-size clasts of aphyric and porphyritic intermediate lava and fragments of siltstone and claystone in a matrix of coarse sand to clay. Also contains discontinuous beds of tan-gray to light-brown, light-brown-weathering, coarse conglomerate and thin interbeds of coarse-grained tuffaceous sandstone containing abundant grains of feldspar, altered ferromagnesian minerals, and minor quartz. Locally present are mudflow breccia deposits containing intermediate lava clasts in biotite-bearing epiclastic matrix and log-size and smaller fragments of petrified wood. Unit underlies potassium-rich andesite, latite, and basalt lava (Tl) exposed along lower Challis Creek (44°34.5′ N., 114°18′ W.). May be correlative with intermediate lava and breccia of mixed zone (Tmz) exposed in Corral Creek cauldron segment. Thickness 0–130 m

Tdf **Dacitic and rhyodacitic lava**—Rhyodacite lava and agglomerate exposed southeast of Challis Creek near Corkscrew Mountain (44°32′ N., 114°23′ W.) and north of Challis Creek (44°36′ N., 114°20′ W.) between Pats Creek and Eddy Creek. Dark-brown-weathering, brown to gray, porphyritic, locally vitrophyric, massive rhyodacite lava and coarse agglomeratic breccias containing 0.2–3 m blocks of monolithologic rhyodacite porphyry in matrix of glassy to devitrified rhyodacite. Phenocrysts (28–44): pf (as much as 5 mm long), 60–75; b, 1–14; px (both opx and cpx), 7–35; hb, 0–13. Contacts between massive and agglomeratic phases of unit are irregular and commonly steep. Cavities filled with chalcedonic silica locally abundant. Biotite from sample collected from southwest side of Corkscrew Mountain (44°32′ N., 114°23′ W.) has potassium-argon age of 50.4±1.8 m.y. (see table 1). For additional description, see p. 8, 15, and 18

Tvs **Volcaniclastic and sedimentary rocks**—For description, see p. 15 and 18

Custer graben area

Intrusive rocks

Tdi **Dikes and plugs of intermediate composition**—Brown- and reddish-brown-weathering, crystal-poor rocks that contain phenocrysts less than 2 mm in length of plagioclase, amphibole or pyroxene, and minor biotite

Trd **Rhylolite dikes**—These rocks occur outside Custer graben to south and west. For description, see p. 19

Td **Dikes**—Gray, brownish-gray and greenish-gray, holocrystalline, medium- to fine-grained dike rocks, primarily gabbro and diabase, made up chiefly of plagioclase and clinopyroxene; pyroxene commonly partly or wholly altered to chlorite. Have reversed magnetic polarity

Tr **Rhyolite intrusions**—Gray, white, and pink dikes, plugs, and domes that contain phenocrysts of alkali feldspar and quartz, and minor amounts of biotite and plagioclase

Tgi **Intrusive rocks east of Bonanza**—Porphyritic to equigranular rocks that range in composition from granodiorite to quartz monzonite. Major element analysis of quartz monzonite resembles analysis of tuff of Eightmile Creek (Tem). Rocks exposed are in roof zone of pluton intruding intermediate lava (Tdf, see below); blocks of lava are common as inclusions, and in some exposures intrusion more closely resembles swarm of closely spaced dikes cutting lava, as first described by Anderson (1949). Aeromagnetic data and distribution of thin dikes indicate buried extension of intrusion for at least 3 km west of principal outcrop area. Intrusion and country rock both are propylitized; minor hydrothermal biotite locally developed in intrusion

Extrusive and sedimentary rocks

Trl **Rhyolite lava**—Gray and grayish-red, chiefly crystal-poor rhyolite containing phenocrysts of alkali feldspar and quartz. On ridgecrest east of upper Basin Creek (44°22′ N., 114°53′ W.) it is unaffected by faults that offset underlying volcaniclastic rocks (Tps) and intermediate lava (Tdf)

Tpc **Tuffs of Pennal Gulch and Camas Creek–Black Mountain, undivided**—Nonwelded tuff sequence that overlies tuff of Eightmile Creek (Tem, see below) in Custer graben, chiefly east of Jordan Creek. Locally includes tuff of Ninemile Creek (McIntyre and others, 1982), a densely welded unit not shown separately on this map, and debris possibly derived from rhyolite domes in upper Jordan Creek area (44°26′ N., 114° 44′ W.) (Foster, 1982). Thickness more than 600 m

Tvc **Volcaniclastic rocks**—Ash-flow and ash-fall tuff that overlies tuff of Eightmile Creek west of Bonanza (44°23′ N., 114°43.5′ W.). Coarser grained rocks in this unit are characterized by crystals of plagioclase, sanidine, and quartz (quartz more abundant than sanidine in most places); biotite is only mafic mineral present. On ridge west of Lightning Creek (44°25.5′ N., 114°49′ W.), thin flow of intermediate lava occurs within the unit. For additional description, see p. 17

Tem **Tuff of Eightmile Creek**—Gray, greenish-gray, pale-brown, and grayish-pink, bluff-forming, pumice-rich, crystal-rich, densely welded, quartz latitic ash-flow tuff characterized by phenocrysts, as much as 4 mm long, of plagioclase, quartz, sanidine, biotite, amphibole, clinopyroxene, orthopyroxene, zircon, apatite, and allanite. Biotite from vitrophyre exposed west of mouth of Tenmile Creek (44°28′ N., 114°35′ W.) has potassium-argon age of 47.5±1.3 m.y. (see table 1); this age supersedes previously published age of 46.9±1.6 m.y. (McIntyre and others, 1982). Unit has reversed magnetic polarity. On west side of Eightmile Creek about 4 km above its mouth (44°27′ N., 114°39′ W.), four cooling units having total thickness of more than 215 m are exposed. For additional description, see p. 8, 9, and 13

Trm **Rhyolite of Mill Creek Summit**—For description, see p. 17

Tdf **Dacitic and rhyodacitic lava**—In Custer graben consists chiefly of crystal-poor, potassium-rich andesite that contains phenocrysts, generally smaller than 2 mm long, of plagioclase and clinopyroxene. Characterized by propylitic alteration in Sunbeam mine-Estes Mountain area (44°27′ N., 114°44′ W.) and in area surrounding Custer (44°23.5′ N., 114°41′ W.). For description, see p. 8 and 14

Tvs **Volcaniclastic and sedimentary rocks**—Volcanic sandstone, conglomerate, siltstone, and mudstone exposed northeast of Basin Creek. The coarsest grained rocks in lower part of unit, which include volcanic sandstone, conglomerate, and massive, pumice-rich pyroclastic flow more than 15 m thick, contain crystals of plagioclase, sanidine, quartz, and biotite. Rocks higher in unit lack sanidine and contain plagioclase, quartz, biotite, and hornblende. Beds of nonvolcaniclastic arkosic sandstone locally present in upper part of unit

Tar **Arkosic sandstone and conglomerate** —Gray arkosic sandstone and local beds of conglomerate that contains pebbles and cobbles of gray quartzite. Occurs as discontinuous lenses at base of sequence east of Basin Creek (44°18′ N., 114°51′ W.). Many occurrences too small to be shown at this map scale

Southeastern part of quadrangle

Intrusive rocks

Rhyodacite domes and plugs at Bradbury Flat —Black, columnar-jointed, glassy rhyodacite and gray, grayish-brown, or red-purple devitrified rhyodacite containing as much as 30 percent phenocrysts as much as 4 mm long of plagioclase, orthopyroxene, clinopyroxene, biotite, apatite, and opaque oxides

Tdbi **Rhyodacite plugs**—Cross-cutting plugs of rhyodacite in bluff exposures along Salmon River west of Bradbury Flat (44°26′ N., 114° 10′ W.) and in hills north and east of Bradbury Flat. Have normal magnetic polarity. Northeast-dipping slab of similar rock at southwest margin of Bradbury Flat has reversed magnetic polarity

Tdb **Rhyodacite domes**—Irregularly shaped domelike masses of rhyodacite in hills northwest of Bradbury Flat. Potassium-argon age for columnar-jointed rhyodacite exposed at northwest margin of Bradbury Flat is 39.7±1.2 m.y. (see table 1)

Tib **Mafic intrusive rocks**—Olivine-bearing intrusive rocks that have been mapped separately only along Road Creek (44°10′ N., 114° 10.5′ W.), and Horse Basin Creek

Tdl **Diabase and lamprophyre dikes**—Similar to dikes described on page 19, except that in this area, trends are primarily northeast rather than northwest

Til **Potassium-rich andesite, latite, and basalt intrusions**—Dikes, sills, and plugs that commonly consist of brown- or reddish-brown-weathering, dark-gray, greenish-gray, or black, crystal-poor rocks containing variable proportions of phenocryst minerals clinopyroxene, orthopyroxene, olivine, and plagioclase. Exposed as dikes, sills, and plugs along Salmon River near Centennial Flat (44°22′ N., 114°16.5′ W.), in region between Summit Rock and Bald Mountain, and as altered, irregularly shaped intrusive masses north of Little Antelope Flat. Near Centennial Flat, intrusive rocks were altered by reaction with wet, semiconsolidated sediments they intruded to produce chlorite-, clay-, and carbonate-rich, light-greenish-gray rocks. Whole-rock potassium-argon age for the unaltered part of one intrusive mass is 48.2±1.4 m.y. (see table 1). Magnetic polarities are normal and reversed

Tsy **Syenite intrusion**—Irregularly shaped, sill-like mass of medium- to coarse-grained syenite that crops out east of Tub Spring, in upper Spar Canyon (44°15.5′ N., 114°11′ W.). Rock contains potassium feldspar, clinopyroxene, biotite, apatite, and magnetite. Clinopyroxene commonly altered to carbonate; both clinopyroxene and biotite commonly altered to chlorite. Carbonate also occurs as veins. Some, if not most, carbonate may be primary. Marginal facies of intrusion are dark, basalt-like rocks containing altered olivine phenocrysts; thin sections show that these rocks have holocrystalline matrices made up chiefly of alkali feldspar and biotite. Emplacement of intrusion probably penecontemporaneous with eruption of nearby latite lava (Tl, see p. 17)

Tdi **Dikes and plugs of intermediate composition**—Intrusive equivalent of intermediate lava (Tdf, see p. 18). Most prominent occurrence is near Sheep Mountain (44°04′ N., 114°22′ W.), where swarm of dikes probably marks site of concealed felsic pluton and source vent for surrounding pyroclastic rocks and intermediate lava (Tdf). Biotite from unaltered vitrophyric dike about 3 km south of mouth of Pine Creek (44°05′ N., 114°22′ W.), north of principal dike swarm, has potassium-argon age of 50.0±1.8 m.y. (see table 1). Large body northwest of Thompson Creek (44°21′ N., 114°36′ W.) has well-exposed intrusive contacts near its western end, but toward east resembles dome or thick flow mass

Extrusive and sedimentary rocks

Tbau **Mafic lava**—Olivine-bearing basaltic lava and associated volcaniclastic rocks that crop out south of Road Creek (44°10′ N., 114°10.5′ W.)

Trr **Tuff of Red Ridge**—Red- and reddish-brown-weathering, grayish-purple or reddish-purple, blocky to platy, crystal-poor ash-flow tuff containing phenocrysts less than 1 mm long of alkali feldspar (chiefly anorthoclase). Vitrophyre at east end of Red Ridge (44° 06′ N., 114°29.5′ W.) contains a few crystals of green pyroxene and amphibole. This unit found only along east flank of White Cloud Peaks (44°11′ N., 114°27′ W.) and in Spar Canyon-Sand Hollow (44°13′ N., 114° 12.5′ W.) area. Thickness 0 to more than 140 m

Tcr **Tuff of Challis Creek, outflow unit**—Red, reddish-purple, yellowish-brown, or gray, densely welded, devitrified ash-flow tuff containing 5–20 percent crystals as long as 3 mm of chatoyant alkali feldspar and smoky quartz in matrix of fine shards. Locally contains abundant pumice. Also contains sparse zircon, allanite, biotite, and a few crystals of plagioclase. Near Challis, single cooling unit overlies an irregular erosion surface carved on underlying tuff of Pennal Gulch (Tp). Two, or possibly three, densely welded cooling units present in Spar Canyon-Sand Hollow area. One of these units may be younger than tuff of Red Ridge (Trr). Unit has normal magnetic polarity. Potassium-argon age of sanidine is 45.0±1.3 m.y. (see table 1)

Tp **Tuff of Pennal Gulch**—Gray, pale-pink, or pale-green, silicic, crystal-poor pyroclastic flows and airfall, both subaqueous and subaerial. Chiefly massive to crudely bedded, pumice-rich, coarse tuff and pumice-lapilli tuff, but also includes beds of sorted, thin-bedded volcanic sandstone and mudstone. Commonly contains crystals as much as 2 mm long of plagioclase, sanidine, and biotite, and subordinate or very minor quartz, amphibole, allanite, zircon, and apatite. Sparse carbonized or silicified plant fragments are present in some pyroclastic flows. Locally in exposures east and north of Round Valley (44° 30′ N., 114°11′ W.) and northwest of Ellis (44°41.5′ N., 114°03′ W.), a ledge-forming vitrophyre as much as 15 m thick consists of black, crystal-poor, perlitic, rhyodacitic glass containing crystals of plagioclase, sanidine, clinopyroxene, and zircon. Some samples contain abundant lithic inclusions. Unit has reversed magnetic polarity. Tuff of Eightmile Creek (Tem) included within basal part of map unit south of Table Mountain (44° 44′ N., 114°12′ W.). Thickness 0 to more than 370 m. For additional description, see p. 13

Tvc **Volcaniclastic rocks**—Ash-flow tuff, thin-bedded volcanic sandstone, siltstone, and mudstone, containing local zones of impure lignite; unit exposed from Little Antelope Flat (44°23′ N., 114°04′ W.) southwestward to Spar Canyon area (44°14′ N., 114° 13′ W.). Coarsest grained rocks in this unit are characterized by crystals of plagioclase, sanidine, and quartz (quartz commonly more abundant than sanidine); biotite is only mafic mineral present. West of mouth of Spar Canyon nonwelded and densely welded ash-flow tuff related to the tuff of Challis Creek are locally present but have not been mapped separately. Subaqueous pyroclastic flow that is probable equivalent of tuff of Eightmile Creek (Tem) crops out in Spar Canyon and in Sand Hollow. Conglomerate containing clasts of quartzite, slate, and granitic rock, in addition to volcanic clasts, caps sequence south of Spar Canyon and is exposed in hills east of Tub Spring (44°15.5′ N., 114° 11′ W.). For additional description, see p. 15

Th **Tuff of Herd Lake**—Red-purple or red-brown, devitrified, flow-laminated, locally lithophysal, crystal-poor rhyolitic rock that contains phenocrysts of plagioclase, biotite, and clinopyroxene 1 mm long. Two cooling units, separated by breccia zone, present north of Herd Lake (44°05′ N., 114°10′ W.). In most places these rocks resemble rhyolite lavas; however, exposure on ridge about 3 km south of Jerry Peak reveals marginal vitrophyre rich in shards. This exposure and sheetlike aspect of deposit indicate that unit was emplaced as very hot ash flow that coalesced and moved like lava prior to final chilling. Biotite from vitrophyre has potassium-argon age of 48.1±1.7 m.y. (see table 1). Map unit has reversed magnetic polarity. Overlies unit Tl. Thickness 0–150 m

Tl **Potassium-rich andesite, latite, and basalt lava**—Predominantly aphyric, reddish-brown-weathering, gray, purple, and greenish-gray, blocky to platy lava, locally containing interbedded oxidized breccia. Olivine and pyroxene occur as phenocrysts in some samples. Plagioclase not commonly found as phenocrysts. Microphenocrysts include olivine, clinopyroxene, orthopyroxene, and sieve-textured plagioclase. Quartz xenocrysts commonly present. Plagioclase-rich groundmass commonly is trachytic or pilotaxitic and may contain apatite and reddish-brown, strongly pleochroic mica. In region surrounding Challis, rock compositions range from potassium-rich andesite to potassium-rich basalt, andesite probably predominating. Farther south, in area between East Fork of Salmon River and Jerry Peak (44°03.5′ N., 114°06.5′ W.), compositions range from potassium-rich andesite to latite. Latite is more common toward top of section. Magnetic polarity indeterminate in area near Challis; lava toward south has reversed magnetic polarity. Near Challis, the lava overlies tuff of Ellis Creek (Te, 48.4±1.6 m.y.) and is overlain by tuff of Eightmile Creek (Tem, 48.4±1.6 m.y. and 47.5±1.3 m.y.) and tuff of Table Mountain (Ttm, 47.8±1.7 m.y.). Toward south, lava overlies tuff dated at 49.0±2.9 m.y. (Tvs) and is overlain by tuff of Herd Lake (Th, 48.1±1.7 m.y.)

Trm **Rhyolite of Mill Creek Summit**—Black, gray, and greenish-gray vitrophyric rhyolite lava and gray to pink, banded, devitrified rhyolite lava containing 1–5 percent phenocrysts, as much as 2 mm in length, of plagioclase and biotite. Also contains hornblende, allanite, zircon, apatite, and opaque oxides. Some flows also contain alkali feldspar and quartz. Four flows that have aggregate thickness of about 235 m are present in butte east of Mill Creek Summit (44°28′ N., 114°29′ W.). Potassium-argon age on biotite is 48.5±1.2 m.y. (see table 1). All flows have reversed magnetic polarity

Tbam **Mafic lava**—Dark, sparsely porphyritic basaltic and andesitic lava, exposed along Salmon River near Centennial Flat (44°22′ N., 114°17′ W.) that contains variable proportions of olivine, pyroxene, or plagioclase phenocrysts. Probably related to mafic intrusive rocks (Til) that crop out nearby

Tvs **Volcaniclastic and sedimentary rocks**—Includes subaqueously deposited pyroclastic flows, mudflow breccia and conglomerate, volcanic sandstone, and mudstone exposed along the Salmon River west and south of Challis, near Centennial Flat, along East Fork Salmon River, along Road Creek, and along Herd Creek. Also includes subaerial ash-fall and ash-flow deposits intercalated with and overlying intermediate lava in and north of Squaw Creek drainage basin (44°22′ N., 114°28′ W.). Volcanic components of all these rocks contain plagioclase, biotite, and amphibole. Quartz is minor and variable in amount. Some samples contain a few grains of pyroxene. Coeval with parts of intermediate lava sequence (Tdf); ranges in age from about 50 m.y. to about 48 m.y. Potassium-argon dating on sample from southeast of Jerry Peak yielded ages of 49.0±1.8 m.y. on biotite and 49.0±2.9 m.y. on hornblende (see table 1). A subaqueous pyroclastic flow, about 12 m thick, that is probable equivalent of tuff of Ellis Creek (Te, 48.4±1.6 m.y.) occurs within this unit in area south of Centennial Flat. Arbitrarily included in this unit are outcrops of pyroclastic flow exposed south of mouth of Squaw Creek that contains significant alkali feldspar, in addition to plagioclase and quartz, and biotite as sole mafic mineral

Tdf **Dacitic and rhyodacitic lava**—Contains heterogeneous group of rocks erupted from numerous vents scattered over area from Challis to south edge of quadrangle. Individual, local units generally can be consistently distinguished during mapping at large scales (see, for example, Hobbs and others, 1975). Compositions mainly dacite and rhyodacite; contain as phenocrysts various combinations of the minerals plagioclase, biotite, amphibole, clinopyroxene, orthopyroxene, and, uncommonly, olivine or quartz. Includes minor amounts of potassium-rich andesite characterized by phenocrysts of pyroxene and(or) olivine. Has normal and reversed magnetic polarity. Ranges in age from about 49 m.y. to about 51 m.y. Potassium-argon ages on biotite are 49.2±1.2 m.y. and 51.1±1.7 m.y.; plagioclase is dated at 49.3±1.4 m.y. (see table 1). For additional description, see p. 8, 14, and 15

Tbal **Mafic lava**—Dark, sparsely porphyritic basaltic and andesitic lava that crops out below, and is interbedded with, flows of intermediate-composition lava (Tdf) in hills southwest of Challis. Mafic lava contains variable proportions of olivine, pyroxene, and plagioclase phenocrysts. Sample from Garden Creek (44°29.5′ N., 114°19′ W.), west of Challis, has whole-rock potassium-argon age of 50.3±1.5 m.y. (see table 1)

Tgc **Tuff of Germania Creek**—Densely welded, vitrophyric ash-flow tuff and associated volcanic sediments exposed in ridges northwest and southeast of Germania Creek (44°01′ N., 114°32′ W.). Includes "ignimbrite of Germania Creek" of Motzer (1978). Ash-flow tuff contains as much as 40 percent phenocrysts, as long as 1 mm, of plagioclase, amphibole, clinopyroxene, orthopyroxene, and biotite. Mafic phenocrysts make up more than 40 percent of total phenocrysts. Ash-flow tuff resembles tuff of Burnt Creek (Tbc, below) except for preponderance of amphibole. More thorough sampling may show that this characteristic is not consistent. Has reversed magnetic polarity

Tbc **Lava and ash-flow tuff of Burnt Creek**—Dacitic lava and ash-flow tuff, locally vitrophyric, but commonly rusty brown and devitrified, containing phenocrysts of plagioclase, orthopyroxene, clinopyroxene, amphibole, and biotite. More than 40 percent of total phenocrysts in ash-flow tuff commonly are mafic minerals. Presence of one thin ash-flow tuff cooling unit that has these mineralogic features within tuff of Sage Creek (Tsc) in Sage Creek drainage basin (44°05′ N., 114°05′ W.) shows that the two units are contemporaneous, despite large contrast in composition. Probably has normal magnetic polarity

Tsc **Tuff of Sage Creek**—Ash-flow and ash-fall tuff and associated sedimentary rocks characterized by phenocrysts of plagioclase and sanidine, together with minor biotite, amphibole, and rare pyroxene. Quartz not present. Exposed chiefly near southeast corner of quadrangle in the drainage basin of Sage Creek, and on ridge south of Sheep Mountain. There are isolated outcrops of this rock type, too small to show on map, opposite mouth of Spar Canyon, east of lower Herd Creek, and along East Fork of Salmon River northwest of mouth of McDonald Creek (44°08.5′ N., 114°19′ W.). At all these localities, these rocks crop out beneath volcaniclastic rocks mapped as Tvs. Near Sheep Mountain, tuff of Sage Creek is mixed with breccia and intermediate lava (Tdf); contact between the two units is arbitrary. In some samples of breccia containing blocks with phenocrysts of plagioclase, quartz, biotite, and amphibole, dominance of matrix by crystals of plagioclase and sanidine demonstrates intermingling of material from two sources. Has normal magnetic polarity

Tcg **Conglomerate and fanglomerate**—Chiefly cobble and boulder (as large as 2 m in diameter) conglomerate; black, pink, gray, or white quartzite clasts predominate near base, and volcanic clasts predominate near top. Matrix of conglomerate contains volcanic component throughout. Locally includes pyroclastic flow that contains lava blocks containing plagioclase, biotite, amphibole, and quartz phenocrysts. Present only near southeast corner of quadrangle. Also included in this unit is prevolcanic fanglomerate exposed southeast of Lone Pine Peak (44°21′ N., 114°10′ W.). Clasts in fanglomerate were derived from nearby exposures of Paleozoic rocks, which formed topographically high ridges prior to volcanism

Western and south-central parts of quadrangle

Intrusive rocks

Tdl **Diabase and lamprophyre dikes**—Diabase dikes are the more common. Rock is dark and fine to medium grained; consists chiefly of lathlike crystals of plagioclase enclosed in matrix of pyroxene crystals. Diabase dikes are youngest dikes and crosscut all others. They are the most continuous and commonly trend northwest. Lamprophyric dikes are dark gray to black, fine grained, and somewhat porphyritic; commonly range from a few centimeters to a meter or so in width and are only a few meters in strike length. Augite, brown hornblende, biotite, and plagioclase are principal minerals of this rock, which is a young rock but its relation to the diabase is unknown

Trd **Rhyolite dikes**—Rocks are light colored and generally porphyritic, containing rounded and embayed quartz phenocrysts. Potassium feldspar phenocrysts are more plentiful than plagioclase. Matrices are pinkish gray and aphanitic. Modal compositions include rhyolite, quartz-latite, and rhyodacite. The rocks are altered: sericite is developed from feldspars and iron oxides from pyrite. Dikes range from a few meters to more than 30 m wide and are as much as several hundred meters long. Rhyolite dikes are more numerous near bodies of granite (Tg), to which they probably are related, and, like that rock, are more radioactive than other plutonic rocks or dikes. Granophyric matrices common in dikes cutting Idaho batholith rocks north of Stanley. Some dikes in that area also are composite, having marginal zones more mafic than rhyolite

Tri **Rhyolite stock**—Red-weathering, yellowish-gray, aphanitic rhyolite that contains sparse phenocrysts of quartz as long as 1 mm and pyrite or pyrite casts. Forms massive outcrops. Rhyolite is well exposed on ridge southeast of Cape Horn Creek (44°21.5′ N., 115°11.5′ W.), where stock contains roof pendants of granodiorite (Kgd, see p. 21) and metasedimentary rocks (rp, see p. 26)

Td **Dikes**—Rocks are dark green to gray and commonly porphyritic, containing phenocrysts of zoned plagioclase as long as 2 cm; compositions are primarily andesite, dacite, and latite. Phenocrysts of hornblende, somewhat altered to chlorite, and euhedral biotite also commonly present. Quartz phenocrysts are sparse. Phenocrysts are set in groundmass of andesine-oligoclase, minor potassium feldspar, hornblende, and magnetite. Sphene and allanite are common accessories. Dikes range from a few meters to more than 30 m wide and are as much as several hundred meters long. They are more numerous near exposures of Tertiary diorite complex (Tdc), to which they probably are related

Tdu **Tertiary dikes, undivided**—Rhyolite to diabase dikes

Tg **Granite**—Pink to gray, medium- to coarse-grained granite characterized by pink perthitic feldspar. Relative proportion of salic minerals (calculated from the CIPW norm): q, 39; af, 34; pf, 27. Rock contains miarolitic cavities, locally lined with smoky quartz crystals, and is more radioactive than granodiorite of Idaho batholith. Hornblende from one sample was dated by potassium-argon methods at 44.3±1.3 m.y. (see table 1). Granite includes part of Sawtooth batholith (Reid, 1963)

Tdc **Dioite complex**—Complex suite of rocks ranging from nonporphyritic diorite to porphyritic granodiorite, which is prevalent. Rock is characterized by abundance of hornblende, euhedral biotite, and magnetite, which together make up as much as 35 percent of it. Phenocrysts in porphyritic rocks are chiefly zoned plagioclase and pale-red perthitic microcline, which may be as long as 1 cm; phenocrysts are set in fine-grained, pale-red matrix. Quartz phenocrysts are rare. Relative proportion of salic minerals (calculated from CIPW norm): q, 19; af (microcline), 21; pf, 60. Rocks weather to chocolate-brown soil, darker than soil formed from granitic rocks of area. Diorite and dark-greenish-gray aphanitic andesitic phases are generally peripheral to porphyritic rock. Biotite, hornblende, and whole-rock potassium-argon ages for three samples collected in Jackson Peak (44°05′ N., 115°25′ W.) and Monumental Peak areas are 46.2±0.9 m.y., 46.6±0.5 m.y., 47.7±1.1 m.y., 48.2±3.0 m.y., and 46.0±1.7 m.y. (see table 1). In some areas this unit is mapped to include large numbers of andesite, dacite, and latite dikes (Td)

Tgp **Gray porphyry**—For description, see p. 2, 5, and 10

Extrusive rocks

Twt **Welded tuff of Obsidian**—Light-gray welded lithic tuff exposed north of Obsidian, near south edge of quadrangle. Weathers reddish purple, brownish gray, and brown. Rock is light-gray ash-flow tuff that contains phenocrysts of sanidine and quartz in a fine, light-gray matrix

Tva **Andesite**—Dark-gray to black, thinly layered, flow-banded, aphanitic lava that has pilotaxitic texture. Contains olivine phenocrysts, rimmed by iddingsite, set in groundmass of andesine microlites and interstitial pyroxene and magnetite. Overlies rhyolitic flows where exposed on ridge top between Knapp and Beaver Creeks (44°25′ N., 115°05′ W.)

Tvr **Rhyolite flows**—Yellowish-gray to pale-red to purple, aphanitic lava that commonly shows flow-banding and flattened quartz-lined vugs along flow laminae. Contains phenocrysts of platy sanidine and rounded, embayed quartz. Rock erodes to conspicuous massive knobs on ridge line and to reddish, slabby scree. Includes minor amounts of rhyolitic tuff. Sanidine has a potassium-argon age of 37.6±2.1 m.y. (see table 1). Geologic relations suggest that this age is too young. Preserved in a graben between Knapp and Beaver Creeks (44°23′ N., 115°08′ W.)

Tcv **Challis Volcanic Group, undivided**—Includes three small ridge caps of rhyolite and discordant rhyolitic tuff near headwaters of North Fork of Boise River (44°05′ N., 115°11′ W.) and, in northern part of area, exposures on headwaters of Rapid River (44°40′ N., 115°02′ W.) and on headwaters of Riordan Creek (44°49′ N., 115°24′ W.)

CRETACEOUS INTRUSIVE ROCKS

Ki **Granitic rocks of Idaho batholith, undivided**

Klg **Leucocratic granite**—Light-gray to white, fine- to medium-grained granite having distinctive anhedral texture. Principal minerals are quartz (33 percent), potassium feldspar (29 percent), and plagioclase (An_{26-30}, 33 percent). Biotite may constitute as much as 2 percent of rock, garnet is common, and feldspars are altered to sericite and small irregular flakes of muscovite. This rock, described as leucocratic quartz monzonite by Reid (1963) and by Kiilsgaard and others (1970), as aplite by Cater and others (1973), and as aplitic quartz monzonite by Anderson (1947), occurs as dikes and irregularly shaped stocks that are resistant to erosion and tend to form high points on ridges. Rubbly, weathered scree from these high points may be extensive on lower hillsides and may give the impression of being eroded from larger masses than actually exist. Intrudes biotite granodiorite (Kgd, see below) and is itself intruded by Tertiary granite (Tg) and stocks of Tertiary diorite complex (Tdc). It also occurs as small dikes and plugs intrusive into biotite granodiorite and granite (Kgd, see below) in exposures along east side of Stanley Basin. Potassium-argon ages of biotite from five samples range from 63.6±1.4 to 72.6±2.5 m.y. (see table 2)

Kg **Muscovite-biotite granodiorite and granite**—Gray to light-gray, medium- to coarse-grained, equigranular to porphyritic granodiorite; contains books of muscovite that are visible in hand specimen and make up as much as 5 percent of rock. Except for visible muscovite, rock is similar to biotite granodiorite (Kgd), with which it is transitional through zone about 2 km or more wide. It is exposed in western part of quadrangle and comprises what is considered to be core of Atlanta lobe of Idaho batholith. Includes quartz monzonite of Warm Lake of Schmidt (1964). Potassium-argon ages of nine samples range from 65.3 to 73.9±2.7 m.y. for biotite and from 68.8±0.2 to 74.7±2.7 for muscovite (see table 2)

Kgd **Biotite granodiorite**—Gray to light-gray, medium- to coarse-grained, and equigranular to porphyritic rock. Plagioclase (An_{22-30}) is chief component of rock, which has lesser quantities of quartz and potassium feldspar. Biotite is principal mafic mineral, constituting as much as 5 percent of rock in most places; however, east of Stanley Basin it makes up 25 percent of rock. Hornblende is rare. Biotite granodiorite is most common granitic rock of Idaho batholith and is exposed over vast areas. In western part of quadrangle rock was identified by Schmidt (1964) as granodiorite of Gold Fork. Biotite granodiorite is intruded into older tonalite (Kt, see below) and in the 60- to 90-m-wide contact zone it exhibits intensive primary foliation as well as xenoliths of tonalite. Includes foliated diorite in Loon Creek (44°35′ N., 114°51′ W.) and at mouth of Camas Creek (44°53′ N., 114°44′ W.). Potassium-argon ages of biotite range from 61.5 to 98.1±3.3 m.y. (see table 2)

Kgds **Sphene-enriched biotite granodiorite**—Mapped by Schmidt (1964) as leucocratic quartz diorite of Little Valley

Kgdp **Porphyritic biotite granodiorite and granite**—Coarsely porphyritic granitoid rock containing metacrysts of pink potassium feldspar (microcline) from 3 to 10 cm long in medium- to coarse-grained matrix that contains roughly equal amounts of microcline, plagioclase, and quartz; generally 5–15 percent biotite and variable amounts of hornblende. Foliation commonly present and locally strongly developed in area west and north of Stanley Basin. Also included in this unit are rocks that form cores of stock at White Cloud Peaks and large pluton east of Stanley Basin. In those areas rocks are unfoliated porphyritic biotite granite and biotite granodiorite that contain metacrysts of microcline 1–3 cm long in medium-grained granitoid matrix containing predominantly 5–10 percent, and rarely as much as 20–25 percent, biotite and approximately equal amounts of quartz, potassium feldspar, and plagioclase. Equigranular margins of two bodies are separated from porphyritic granite cores by potassic metasomatized transition zone as much as 1.5 km wide that contains abundant veins and pods of potassium feldspar and locally abundant secondary muscovite that coats joints. Potassium-argon ages of biotite from four samples range from 62.6 to 84±2 m.y. (see table 2)

Kgdh **Hornblende-biotite granodiorite**—Gray, medium- to coarse-grained, equigranular to porphyritic, commonly foliated granodiorite; biotite and hornblende are aligned in plane of foliation. Rock commonly is associated with xenoliths and pendants on high ridges in western part of quadrangle. It is intermixed with tonalite (Kt); the two rock types form border zone of Atlanta lobe of Idaho batholith

Kt **Tonalite and granodiorite**—Gray to dark-gray, medium- to coarse-grained, equigranular to porphyritic rock. Plagioclase (andesine) is dominant mineral of rock, some of which contains biotite or hornblende and which ranges from massive to highly foliated. It is exposed in western part of quadrangle, where it includes quartz dioritic gneiss of Donnelly (Schmidt, 1964), and in west-central part of quadrangle in Loon Creek drainage basin (44°32′ N., 114°51′ W.). East of Stanley and southwest of mouth of Warm Spring Creek (44°08′ N., 115°58′ W.) this unit is equigranular, medium-grained, granitoid rock containing 30–35 percent amphibole laths, 40–50 percent plagioclase, and about 20 percent quartz. Amphibole is partly altered to brown, highly pleochroic biotite and to epidote. Sphene is principal accessory mineral. Potassium-argon ages of biotite from three samples range from 71.9±2.5 to 81.6±2.9 m.y. (see table 2)

Kim **Mixed rock units**—Mainly alaskite that encloses Precambrian metamorphic xenoliths

JURASSIC INTRUSIVE ROCKS

Jg **Gabbro**—Dark-grayish-green, medium- to coarse-grained rock containing primary mineral assemblage of calcic plagioclase, clinopyroxene, and magnetite, whose texture is overprinted by alteration assemblage of chlorite, pale-green acicular amphibole, albite, sphene, and small amounts of apatite, prehnite(?), pumpellyite(?), carbonate and(or) secondary quartz. Occurs as numerous small, irregular dikes, small plugs, and sill-like tabular masses scattered over area east and northeast of Clayton. Most commonly found intruded along or near thrust fault at base of Clayton Mine Quartzite (O€q). Fission-track age of 140.1±17.4 m.y. was obtained from zircon in quartzite immediately adjacent to contact with gabbro at mouth of Bayhorse Creek (44°22.5′ N., 114°15′ W.) (R. A. Zimmermann, written commun., 1983). This age for the zircon indicates time of track annealing caused by heat from gabbro intrusion. It also serves as limiting age for thrust fault beneath Clayton Mine Quartzite,

already in existence prior to intrusion of gabbro

PALEOZOIC SEDIMENTARY ROCKS

Pg **Grand Prize Formation (Lower Permian)**—Well-exposed sequence of fine-grained, dark-gray, carbonaceous argillite, siltite, limy siltite, and silty limestone. Weathers dark brown, reddish brown, or dark gray. Much of sequence is graded and has abundant crossbedding, convolute structures, and prominent banded appearance. Measured section on north side of Pole Creek at confluence with Grand Prize Creek (43°56′ N., 114°41′ W.) at type locality in Hailey 1°×2° quadrangle is about 2,000 m thick, but neither top nor bottom is exposed. Conodonts collected by C. M. Tschanz from low in section at Pole Creek are reported to be Leonardian-Roadian (upper Lower Permian) by Bruce Wardlaw (written commun., 1979). On Pungo Mountain a sequence about 100 m thick of thin-bedded limestone and calcareous argillite that have been extensively metamorphosed to tremolite-actinolite is questionably assigned to this unit. Sequence forms black soil. Mapped to include clean, well-sorted quartzite on east side of Pungo Mountain

Wood River Formation

PPw **Upper part (Lower Permian to Upper Pennsylvanian)**—Includes units 5 and 6 of Hall and others (1974). Thick sequence of gray and light-brown, fine-grained, calcareous sandstone that weathers dark brown and dark reddish brown. Interbedded in calcareous sandstone are fine-grained sandy limestone, fine- to medium-grained bioclastic limestone, and brown, thick-bedded, fine-grained quartzite. Crossbedding and convolute structures are common. Unit is dated on basis of abundant fusulinids. Minimum thickness 3,400 m at type locality (Hall and others, 1974)

Pwl **Lower part (Upper to Middle Pennsylvanian)**—Includes units 1, 2, 3, and 4 of Hall and others (1974). Lower part of Wood River Formation is present only from Railroad Ridge (44°08.5′ N., 114°35.5′ W.) at Little Livingston and Hermit mines south to Livingston mine. Unit 1 is chert and quartzite conglomerate present as thin fault slivers at Little Livingston and Hermit mines. It is overlain by succession about 150 m thick of fine-grained limy sandstone, silty limestone, and limy siltstone that includes units 2, 3, and 4

Pzsr **Salmon River assemblage (Paleozoic)**—Medium- to dark-gray, thin- to thick-bedded, well-laminated argillite, siltstone, calcareous siltstone, and fine-grained calcareous sandstone; some local grit and nearly pure, medium-gray limestone. Weathers tan, medium brown to dark brown, and, locally, light gray, blue gray, and pink. Sandstone is predominantly very fine to fine grained; some medium sand and grit layers; localized thin beds of chertlike, very siliceous argillite. Rock composed of variable proportions of quartz (predominant), clay minerals, carbonaceous material, sericite, mica, feldspar (usually only few percent), lithic fragments (argillite, shale, chert, fine-grained quartzite), various accessory minerals, and carbonate. Faint to prominent lamination in most places; cross lamination, current bedding, and sole structures in many fine-grained, thin sandstone beds and laminae. Dark colors related to amount of carbonaceous material, which ranges from nil to nearly 100 percent in few impure, coaly seams. Age of this assemblage is poorly known. Megafossils recovered from blocks of float found near mouth of Mill Creek (44°15′ N., 114°33′ W.) were assigned a Mississippian age (Hobbs and others, 1975). Conodonts collected from lower Thompson Creek (44°16.5′ N., 114°31′ W.) and from Slate Creek (44°12′ N., 114°36′ W.) have Late Cambrian and Devonian ages (J. Repetski, written commun., 1984). Base of sequence as exposed in quadrangle is thrust fault; overthrust by Grand Prize Formation (Pg) between Warm Springs and Slate Creeks (44°13′ N., 114°38′ W.) and by Wood River Formation (PIPw and Pwl) near Washington Peak (44°01′ N., 114°00′ W.). Thickness and sequence of units indeterminate in most places because of isoclinal folding and thrust faulting. About 1,400 m is present along Last Chance Creek (44°11.5′ N., 114°37′ W.), but neither base nor top is exposed

Msuc **Surrett Canyon and South Creek Formations, undivided (Upper Mississippian)**—Gray, fossiliferous, pure, thick-bedded, cliff-forming limestone and grayish-red-purple, impure, thin-bedded, slope-forming limestone. Top not exposed in quadrangle. Thickness about 400 m in area to east (Mapel and others, 1965)

Msp **Scott Peak Formation (Upper Mississippian**—Medium-dark-gray, chert-bearing bioclastic limestone; weathers medium dark to medium light gray; chert medium dark to medium gray, weathers brownish tan, forms discontinuous thin layers and nodules scattered along bedding. Medium to thick bedded. Forms ledges. Contains much crinoidal debris, many corals, and brachiopods. Locally contains jasperoid (black silica as replacement of carbonate rocks). Evidence obtained elsewhere in region indicates that this material was formed during or after Eocene volcanism (B. A. Skipp, oral commun., 1983). Fragments of what appears to be this material within conglomerate at base of volcanic sequence (Tcg) suggest that jasperoid in this area may be both older than and penecontemporaneous with the volcanic rocks. Present only in southeast corner of quadrangle. Thickness about 750 m

Mmc **Middle Canyon Formation (Upper and Lower Mississippian)**—Succession of medium-bedded cherty limestone and impure limestone exposed as smooth, float-covered slopes in southeast corner of quadrangle. Upper half is impure, medium-dark-gray to medium-gray, cherty, microgranular limestone. Black chert abundant in layers and nodules. Weathers to medium- or light-gray, small, irregularly shaped blocks that have slight yellow or pink mottling. Lower half is very fine grained sandy limestone, silicified in part. Float in lower half is more brightly colored and more angular than that of upper part. Locally, limestone is replaced by jasperoid; see discussion under Scott Peak Formation (Msp), above. Thickness about 200 m

Mw **White Knob Limestone (Upper Mississippian)**—Chiefly gray, ledge-forming, thick- to thin-bedded fossiliferous limestone; locally sandy, variably cherty, but in middle part also includes gray to yellowish-brown chert and quartzite granule to cobble conglomerate, sandstone, siltstone, and mudstone. Locally, limestone is replaced by jasperoid; see discussion under Scott Peak Formation (Msp), above. Thickness about 1,150 m

Mmg **McGowan Creek Formation (Lower Mississippian)**—Poorly exposed unit of mudstone (or argillite), subordinate siltstone, partly calcareous claystone, sandstone, and minor pebble conglomerate. Extensively sheared; formation sustains steep slopes covered by slabby or platy, locally finely blocky or pencil-like fragments; weathers medium light gray, yellowish gray, or light olive gray. Measured thickness 1,100 m in Lost River Range, east of quadrangle (Mapel and others, 1965; Sandberg, 1975)

Mcb **Copper Basin Formation, lower part (Lower Mississippian)**—Light-gray to black, medium- to thick-bedded conglomerate, sandstone, siltstone, and mudstone. Conglomerate contains clasts as much as 20 cm in diameter of chert, quartzite, quartz, and argillite in sandstone matrix. Unit is series of proximal to distal turbidites (Nilsen, 1977). Crops out chiefly near southeast corner of quadrangle. An isolated outcrop at confluence of Herd Creek and Lake Creek (44°07′ N., 114°14.5′ W.) is questionably assigned to this formation. Thickness more than 300 m

Dgj **Grand View and Jefferson Dolomites, undivided**

Dg **Grand View Dolomite (Upper Devonian)**—Includes microgranular, medium-dark- to medium-light-gray dolomite that weathers medium light gray and lighter and much recrystallized medium-light-gray to very light gray, fine- to coarse-grained dolomite that weathers grayish orange or pale yellowish brown. Scattered sandy intervals; a few shaly beds. Beds thick, commonly laminated. Formation moderately to highly resistant; forms blocky ledges and, locally, cliffs. At south end of, and southwest of, Grand View Canyon (44°21.5′ N., 114°3.5′ W.) map unit includes small patches of calcareous shale and dolomite elsewhere assigned to overlying Three Forks Formation (Hays and others, 1978). Thickness about 365 m

Dj **Jefferson Dolomite (Upper and Middle Devonian)**—Resistant, well-exposed unit of medium-dark-gray to medium-gray and subordinate dark-gray dolomite. Weathers to similar dark colors, partly mottled, commonly having brown cast; a few beds weather medium light gray. Grain size ranges from microgranular to fine; little silt or sand; commonly fetid. Beds thick to very thick (0.3–1.5 m); some thin, regular lamination. Highly resistant, forms ledges and cliffs. Thickness about 300 m

Dab **Informal units B (Middle? and Lower Devonian) and A (Lower Devonian) of Hays and others (1978, 1980) and Beartooth Butte Formation (Lower Devonian), undivided**—Unit B contains dark-gray to olive-gray, medium-bedded to very thick bedded dolomite and minor dolomitic sandstone; unit A contains dark- to light-gray, medium- to thick-bedded, moderately silty dolomite; Beartooth Butte Formation contains gray and brownish-gray, medium- to thick-bedded, very fine grained quartzite, sandstone, and siltstone

Sl **Laketown Dolomite (Silurian)**—Strikingly light colored dolomite that commonly forms ridges and peaks. Dolomite is predominantly medium light to light gray, mostly very fine to fine grained, and almost pure. Few scattered sandy intervals. Beds medium to very thick, mainly 0.3–1 m; locally, rock is massive and bedding is obscure. Joints common. Resistance to erosion high; forms rounded, light-gray to very light gray ledges and cliffs. Thickness 215–395 m

Srm **Roberts Mountains Formation (Silurian)**—Medium-dark- to medium-gray, carbonate-bearing, fine-grained detrital rocks and impure carbonate rocks. Most are mudstone, siltstone, and very fine silty sandstone, mainly dolomitic, partly calcareous; less abundant and irregularly distributed are muddy, silty, or finely sandy microgranular to very fine grained limestone and dolomite; small amount of siltite and quartzite. Beds medium to very thick. Regular lamination, 3 mm or less thick, and cleavage that may be parallel or oblique to bedding common. Resistance to erosion moderate to weak. Upper part contains fossils of late Wenlock and probable Ludlow age. Thickness about 800 m in Lone Pine Peak quadrangle (Hays and others, 1978)

Op **Black, carbonaceous, graptolite-bearing shale and argillite (Ordovician)**—Black, fissile, carbonaceous shale; bedding obscured by cleavage. Exposures totalling less than 1 km^2 along lower reaches of Big Lake Creek and Pine Creek (44°09′ N., 114°23′ W.), tributaries to East Fork of Salmon River. Generally deformed, especially in highest exposures beneath thrust contact with Salmon River assemblage (₽zsr). Tentatively correlated with Ordovician Phi Kappa Formation to south, as suggested by Dover and others (1980). Maximum of 35 m of unit exposed, total thickness unknown

Ose **Saturday Mountain Formation, Kinnikinic Quartzite, and Ella Dolomite, undivided (Ordovician)**—Upper and Middle Ordovician Saturday Mountain Formation is predominantly medium-dark- to medium-gray, microgranular to very fine grained, fairly pure dolomite that contains abundant (as much as 50 percent), irregular layers of medium-dark-gray chert in uppermost part of exposed section; some chert color laminated. Weathered surfaces medium light gray with yellowish cast. Forms blocky outcrops strongly ribbed by brownish-weathering chert. Contains considerable limestone, siltstone, and black shale in Squaw Creek area (44°18′ N., 114°29′ W.). Uppermost part of Saturday Mountain Formation may be Silurian. Middle Ordovician Kinnikinic Quartzite is fine-grained quartzite that is mainly light to very light gray with yellowish or brownish cast; locally as dark as medium gray or mottled medium dark and lighter gray; very fine to fine grained, contains some medium-size rounded grains; clean. Medium to thick bedded (maximum 1 m), bedding commonly obscured by shearing and partial recrystallization; local faint lamination. Middle Ordovician Ella Dolomite is medium- to dark-gray or brownish-gray, medium- to thick-bedded dolomite that contains thin laminae of silt and sand. Sequence in extreme northeastern part of quadrangle at

Rattlesnake Creek (44°58′ N., 114°0.5′ W.) includes quartzite that possibly is older than Ella Dolomite. Upper 30 m or so consists of medium-gray, fine-grained, mostly foliated dolomite, locally massive. Lower 10 m includes foliated dolomitic quartzite, which grades downward to massive, cliff-forming, white to light-gray quartzite about 200 m thick consisting of virtually pure quartz in two size fractions, a framework fraction 0.4–0.6 mm in diameter and a matrix fraction 0.1–0.2 mm in diameter. Landreth (1964) noted a few pale-red-purple beds near lower part of unit and considered entire sequence to be Kinnikinic Quartzite. Dolomite sampled by P. J. Modreski from upper 30 m contains conodonts of Middle or Late Ordovician age (J. Repetski, written commun., 1983) and an orthoid brachiopod identified by J. T. Dutro, Jr., (written commun., 1983) as probably genus *Valcourea*. Dutro further suggests that the collection might well represent Ella Dolomite. This allows possibility that quartzite is older than Kinnikinic and equivalent to Lower Ordovician Summerhouse Formation (Ruppel and others, 1975; McCandless, 1982). Total thickness about 1,450 m

Oc **Upper carbonate unit (Ordovician)**—Heterogeneous sequence of dolomite, silty dolomite, and dolomitic sandstone that crops out in Squaw Creek drainage basin, northwest of Clayton. Estimated thickness about 150 m

O€rr **Siltstone, sandy siltstone, and quartzite of Rob Roy mine area (Ordovician? or Cambrian?)**—Thickness of at least 600 m exposed only near Kinnikinic Creek north of Clayton. Top eroded; thrust fault at base

O€q **Quartzite (Lower Ordovician or older)**—Divided into five map units by Hobbs and others (1975). Over most of its outcrop area, consists mostly of Clayton Mine Quartzite (Middle Ordovician or older), which is poorly sorted, coarse- to medium-grained, feldspathic quartzite that, in upper two-thirds of section, includes conglomerate layers, pebbly quartzite, and scattered pebbles. Very thin shale partings throughout. More than 1,000 m thick

Or **Ramshorn Slate (Ordovician?)**—Gray, greenish-gray, purple, thin-bedded, well-laminated slate, locally phyllitic. Commonly shows well-developed cleavage at angle to bedding. Includes thin beds of sandstone toward top. Thick lens of conglomerate at base in outcrops west of Challis. Thickness about 800 m

O€b **Bayhorse Dolomite (Lower Ordovician and Upper Cambrian)**—Light-gray to yellowish-gray, medium-bedded to very thick bedded dolomite in upper part and medium- to dark-gray, thin-bedded, fine-grained limestone in lower part. Dolomite contains dark-gray, silicified oval structures resembling pisolites in several layers as much as 9 m thick. Both upper and lower parts locally contain thin interbeds of siltstone, argillite, or fine-grained sandstone. Top of unit is erosional disconformity characterized by zone of probable paleokarst topography. Minimum thickness about 400 m

€g **Garden Creek Phyllite (Cambrian(?))**—Dark-gray to black, slightly calcareous phyllite. As shown, includes small area of dolomite beneath phyllite, which is exposed in bed of Bayhorse Creek west of Bayhorse. Estimated thickness is 150–300 m

€cqs **Quartzite, shale, and carbonate rocks of Squaw Creek area (Cambrian)**—Includes fossiliferous upper Middle Cambrian shale and underlying sequence of quartzite and carbonate rocks of Cambrian or older age (Hobbs and others, 1968). Mapped as four separate units by Hobbs and others (1975)

PALEOZOIC(?) AND PROTEROZOIC(?) ROCKS

O€Zl **Interbedded quartzite, dolomite, and argillite of Leaton Gulch and Pennal Gulch areas (Ordovician?, Cambrian?, Late Proterozoic?)**—Sequence of predominantly quartzitic strata containing subordinate dolomite interbeds and some thin argillitic interbeds and locally thicker argillite intervals. Quartzite generally deep red to dark purplish gray to medium gray; some thick zones of light pinkish or tannish gray and very light gray to white; medium grays and purplish grays predominate. Thin to medium bedded, platy, laminated; some massive units are thick bedded and structureless; mostly medium to fine grained, locally coarse grained and pebbly; lamination prominent in some thick layers; includes several zones of very coarse conglomerate or intraformational breccia. Much of thin-bedded platy quartzite shows ripple marks, flute casts, worm trails; abundant magnetite in parts of section. Dolomite very fine grained to dense, light to medium tan on fresh surface, weathers rich reddish tan to brown; beds dispersed in quartzite and range from 0.2 m to several meters in thickness; restricted to area within 1 km east from Beardsley Hot Springs (44°31′ N., 114°10′ W.). Argillite occurs as laminae or thin interbeds in much of quartzite sequence and locally forms continuous sequence as much as 100 m thick; generally thin bedded, fissile; dark gray or purplish gray, in places altered to deep gray green. Many argillaceous layers metamorphosed to phyllite close to thrust faults. Sequence of rock types is indeterminate because of complex structure and discontinuity of exposures. General characteristics of strata and structural relations to Swauger Formation suggest possible correlation with Late Proterozoic Wilbert and (or) Lower Ordovician Summerhouse Formations (Ruppel, 1975) or with formation of Tyler Peak of Early Cambrian age (McCandless, 1982)

rp **Roof pendants and xenoliths of metamorphic rock in Idaho batholith, undivided (Paleozoic? or Proterozoic?)**—Includes schist, quartzite, and calc-silicate rocks. At some places graphite is common constituent of rocks. Includes Thompson Peak Formation of Reid (1963)

rps **Schist roof pendant**—Exposures of these rocks east of Big Baldy Lookout (44°47′ N., 114°13′ W.) are principally staurolite-muscovite-biotite-quartz schist and locally, according to B. F. Leonard (written commun., 1983), contain garnet and andalusite

rpq **Quartzite roof pendant**

rpc **Calc-silicate rock roof pendant**

MIDDLE PROTEROZOIC SEDIMENTARY AND METAMORPHIC ROCKS

Yl **Lawson Creek Formation**—Thin- to medium-bedded and interbedded fine-grained, platy, pink to greenish-gray quartzite and dark-purplish-gray quartzitic phyllite containing some zones of laminated purple, sandy argillite. Quartzite is feldspathic, locally containing much coarse mica on bedding planes, and has conspicuous ripple marks and other sedimentary structures. Some thicker quartzite beds similar to Swauger Formation in general characteristics. Base of sequence is gradational through distance of a few meters with the Swauger Formation on which it lies; top not known; minimum thickness about 1,300 m (Hobbs, 1980)

Ys **Swauger Formation**—Light-pink, pinkish-tan, purplish-gray to locally red, medium- to coarse-grained, fairly pure, well-sorted quartzite; commonly contains several percent feldspar; medium to thick bedded, locally prominent cross-lamination; few very thin shaly partings. Base not exposed; top seems to grade over several meters into Lawson Creek Formation (Yl). Minimum thickness about 3,000 m

Yg **Gunsight Formation**—Light-brownish-gray, fine- to medium-grained (0.3–0.6 mm diameter), thin- to thick-bedded, sericitic quartzite; typically contains about 60–65 percent quartz, 30 percent sericite, 2–4 percent orthoclase and perthite, 3–6 percent microcline, 0.4–0.6 percent plagioclase. Rock is not well sorted; mostly well rounded quartz "berries" as large as 0.7 mm commonly occur in matrix of grains averaging about 0.3 mm diameter. Some exposures contain only trace amounts of alkali feldspar and plagioclase and considerably less than 15 percent sericite, and appear to be gradational with overlying Swauger Formation. Thickness 400 m (incomplete)

Ya **Apple Creek Formation**—Mainly siltstone and fine-grained sandstone; medium-greenish-gray to grayish-red-purple to dark-gray, thin-bedded, laminated siltstone containing irregular streaks and lenses of light-gray, pinkish- to pale-brown sandstone cemented by ferrodolomite. Sandstone lenticles are typically a few millimeters to several centimeters thick and 1 m, more or less, long, although much longer lenses are known. Medium-gray to brownish-gray to light-gray or pale-red, feldspathic, fine-grained quartzite beds several centimeters in thickness occur in what appear to be stratigraphically higher parts of unit. Ripple marks and other sedimentary structures are abundant, and many bedding surfaces are coated with detrital mica; lamination and cross-lamination in fine-grained sandstone common. Disconnected exposures and complex structure prevent accurate correlation of beds and determination of thickness. No base or top exposed in quadrangle. It is possible that upper part of section mapped as Yellowjacket Formation (Yy) east and north of Iron Lake (44°54.5′ N., 114°11.5′ W.) and north of Iron Creek (44°56′ N., 114°04′ W.) actually is Apple Creek Formation

Yb **Big Creek Formation**—Light-greenish-gray, thin- and thick-bedded, fine- to medium-grained, micaceous and feldspathic quartzite; thicker beds are conspicuously cross bedded; magnetite grains are abundant in some laminae and scattered through rock. In some exposures greenish-gray quartzite grades upward to reddish-gray feldspathic quartzite that weathers brown and brownish gray. Some thinner bedded exposures contain more siltite and show rather pronounced slaty cleavage, obscure current ripple marks, and some load casts. Typical rocks contain 45–57 percent quartz (0.1–0.3 mm long), 10–20 percent orthoclase and microcline, 10–20 percent plagioclase, and 7–20 percent sericite, biotite, and iron oxide. Abundance of plagioclase is distinctive. Thickness 600 m (incomplete)

Yy **Yellowjacket Formation**—Mostly medium-gray and light-bluish-gray to greenish-gray, thin- and thick-bedded, argillaceous quartzite and siltite grading downward to thin- and thick-bedded, light-gray quartzite that is indistinguishable from underlying Hoodoo Quartzite (Yh, see below). Upper sequence of Yellowjacket Formation (above Hoodoo) along north border of quadrangle at long 114°27′ W. is of uncertain thickness but probably has preserved thickness of several hundred meters. Overall, it is cleaner and lighter colored than Yellowjacket that underlies Hoodoo. Incomplete sequence below Hoodoo in Yellowjacket area (44°59′ N., 114°30′ W.) consists of 2,340 m of dark-gray, argillaceous, thin- and thick-bedded quartzite and siltite that tend to weather to hackly chips. Ross (1934) and our work show that quartzite beds are composed of 55–70 percent quartz grains having average diameter of 0.1 mm, about 30 percent biotite, chlorite, sericite (formed from originally argillaceous material), and magnetite. Some beds are sufficiently rich in magnetite to strongly attract pencil magnet. Argillaceous quartzite grades downward locally to varicolored calcareous rocks. According to Carter (1981), calcareous rocks occur as discrete lenses in argillaceous quartzite. Thin quartzite beds throughout Yellowjacket display fine-scale, cross-laminated layers, oscillatory ripple marks, and current ripple marks. Excellent mud cracks were found in siltite or very thin quartzite layers just east of Yellowjacket Creek, along Hoodoo Creek (44°57.5′ N., 114°35′ W.), and at mouth of Musgrove Creek (45°01′ N., 114°19′ W.) in Elk City 1°×2° quadrangle. These occurrences confirm conclusion of Ross (1934) that Yellowjacket was deposited under shallow marine conditions, at least in area near Yellowjacket mining district (44°59′ N., 114°30′ W.). Base of formation has not been identified in Challis quadrangle. Lower sequence of Yellowjacket in Iron Creek area (44°55′ N., 114°06′ W.) is more than 3,500 m thick; thickness of entire Yellowjacket at principal reference section (Ekren, 1988) is greater than 4,000 m (including Hoodoo Quartzite)

Yh **Hoodoo Quartzite**—White, off-white, and light-brownish-gray, massive-weathering, thin- and thick-bedded, clean quartzite. Except for outcrops at top and base, bedding is obscure; crossbedded in beds 0.5–1.0 m thick; contact at base and top transitional with subjacent and superjacent Yellowjacket. Intensely fractured and sheared in most places. Quartz averages about 85 percent; feldspar averages 5–15 percent and consists of microcline, non-perthitic orthoclase, and sparse albite. Rocks near base and top contain as much as 10 percent biotite, sericite, and iron oxide formed from original clay-rich cement. Thickness 0–1,100 m

INTRUSIVE ROCKS OF UNCERTAIN AGE

dr **Diorite, quartz diorite, and syenite**—In Yellowjacket area corresponds to "hornblende quartz diorite" of Ross (1934), who considered rock to be Tertiary in age. This unit is mixed sequence of mostly gray, melanocratic rock ranging in composition from reconstituted gabbro to mafic-rich quartz monzonite. Composition of gabbro from near Middle Fork Peak (44°58′ N., 114°39′ W.): pf (1–10 mm long), 34.4; b, 2.8; hb (mostly after px), 18.4; fibrous actinolite-tremolite, 5.2; nonfibrous actinolite-tremolite, 15.1; chlorite, 7.6; black opaque oxides, 10.8; apatite, 5.7. According to Ross (1934, p. 58), typical hornblende quartz diorite is nearly white and contains the following minerals: q, trace–5 (locally as much as 20);

af, trace–10; pf, 60; hb and b (mostly intergrown), 20–40 (locally hb, 43; b, 38). Rock commonly is altered to epidote, chlorite, sericite, and calcite. Cater and others (1973) considered these rocks to be Precambrian in age, and Peale (1982, p. 58) considered them to be Cambrian(?) to Ordovician(?). Diorite and quartz diorite are part of composite mass that includes syenite (sr, see below). Gabbro and diabase may be as old as Precambrian, but ages of other rocks of this unit clearly are uncertain. Karl Evans (written commun., 1984) obtained an Ordovician age on zircons from syenite in this map unit from a locality a few kilometers east of Middle Fork Peak (44°58′ N., 114°39′ W.)

sr **Quartz syenite, syenite, and granite**—A composite mass, considered by Ross (1934) to be Tertiary in age. According to Peale (1982, p. 61–62), rocks all contain quartz except for syenite, which is rare. Mode: q, 5–32; af (mostly microcline-microperthite), 37–85; pf, 1–28; b, 0–5; ferrohastingsite, 0–15. Much of rock in this unit is remarkably fresh and postorogenic; it intrudes highly deformed Precambrian rocks. Rock resembles syenite of known Tertiary age elsewhere in quadrangle; in particular, it resembles syenite that is part of intrusive mass at Jackson Peak (Tdc), which intrudes Idaho batholith and has an Eocene potassium-argon age (see page 20). It also closely resembles "hornblende granite" of Ross (1934), which intrudes Challis Volcanics. These rocks presumably are same age as syenite mapped within unit dr (see p. 27)

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Table 1. *Potassium-argon ages of the Eocene Challis Volcanic Group and intrusive rocks*

[All ages calculated using constants of Steiger and Jaeger (1977); ages published prior to 1977 have been recalculated; do., ditto]

Locality No. on map	Map unit symbol	Map unit name (page number)	K-Ar age (m.y.)	Material dated	Sample locality	Sources of data (see list of references)
				Intrusive rocks		
1	(*)	Hornblende latite dike--	36.7±1.5	Hornblende-	Thunder Mtn. cauldron complex--	Leonard and Marvin (1982).
2	Tdb, Tdbi	Rhyodacite domes and plugs at Bradbury Flat (p. 15).	39.7±1.2	Plagioclase---	Southeastern part of quadrangle--	Armstrong (1975).
3	Trd	Rhyolite dikes (p. 2)----	39.8±0.9	Whole rock--	Thunder Mtn. cauldron complex--	Leonard and Marvin (1982).
4	Trd	----------do-----------------	41.1±0.9	Sanidine------	----------------do-----------------------	Do.
5	Trd	----------do-----------------	42.4±1.5	Sanidine------	----------------do-----------------------	Do.
6	Tg	Granite (p. 5)-------------	43.9±1.3	Biotite--------	Northern part of Van Horn Peak cauldron complex.	Armstrong (1975).
			47.8±1.9	Biotite--------	--------------do-------------------------	Leonard and Marvin (1982).
7	Tg	Granite (p. 19)-----------	44.3±1.3	Hornblende-	South-central part of quadrangle.	R.J. Fleck, written commun., 1984.
8	Tqp*	Quartz porphyry intrusions (p. 4).	44.4±1.0	Sanidine------	Panther Creek graben---------------	R.F. Marvin, written commun., 1981.
9	Tr	Rhyolite intrusions (p. 2).	44.6±1.5	Sanidine------	Thunder Mtn. cauldron complex--	Leonard and Marvin (1982).
10	Tr	Rhyolite intrusions (p. 4).	44.6±1.5	Sanidine------	Panther Creek graben---------------	R.F. Marvin, written commun., 1981.
11	Tg	Granite (p. 5)-------------	45.1±1.6	Biotite--------	Northern part of Van Horn Peak cauldron complex.	R.F. Marvin, written commun., 1984.

Table 1. *Potassium-argon ages of the Eocene Challis Volcanic Group and intrusive rocks*--Continued

Locality No. on map	Map unit symbol	Map unit name (page number)	K-Ar age (m.y.)	Material dated	Sample locality	Sources of data (see list of references)
12	Trd	Rhyolite dikes (p. 2)----	45.2±1.5	Sanidine------	Thunder Mtn. cauldron complex--	Leonard and Marvin (1982).
13	Tdc	Diorite complex (p. 20)-	46.0±1.7	Whole rock--	Western part of quadrangle--------	R.J. Fleck, written commun., 1984.
14	Tdi	Dikes and plugs of intermediate composition (p. 10).	46.0±1.7	Biotite--------	Southern part of Van Horn Peak cauldron complex.	R.F. Marvin, written commun., 1983.
			48.9±2.9	Hornblende-	----------------do-----------------------	Do.
15	Tdc	Diorite complex (p. 20)-	46.2±0.9	Biotite--------	Western part of quadrangle--------	R.J. Fleck, written commun., 1984.
			47.7±1.1	Hornblende-	----------------do-----------------------	Do.
16	Trf	Rhyolite dikes, plugs, and flows (p. 10).	46.5±1.7	Sanidine------	Southern part of Van Horn Peak cauldron complex.	R.F. Marvin, written commun., 1984.
17	Tdc	Diorite complex (p. 20)-	46.6±0.5	Biotite--------	Western part of quadrangle--------	R.J. Fleck, written commun., 1984.
			48.2±3.0	Hornblende-	----------------do-----------------------	Do.
18	Tg	Granite (p. 5)------------	46.6±1.6	Biotite--------	Northern part of Van Horn Peak cauldron complex.	R.F. Marvin, written commun., 1981.
19	Til	Potassium-rich andesite, latite, and basalt intrusions (p. 16).	48.2±1.4	Whole rock--	Southeastern part of quadrangle--	Armstrong (1975).
20	Tgp	Gray porphyry (p. 10)---	48.6±1.4	Biotite--------	Southern part of Van Horn Peak cauldron complex.	Armstrong (1975).
21	Tdi	Dikes and plugs of intermediate composition (p. 16).	50.0±1.8	Biotite--------	Southeastern part of quadrangle--	R.F. Marvin, written commun., 1982.

Table 1. *Potassium-argon ages of the Eocene Challis Volcanic Group and intrusive rocks*--Continued

Locality No. on map	Map unit symbol	Map unit name (page number)	K-Ar age (m.y.)	Material dated	Sample locality	Sources of data (see list of references)
				Extrusive rocks		
22	Tvr	Rhyolite flows (p. 20)---	37.6±2.1	Sanidine------	Western part of quadrangle--------	R.J. Fleck, written commun., 1984
23	Tcr	Tuff of Challis Creek (p. 16).	45.0±1.3	Sanidine-----	Southeastern part of quadrangle--	Armstrong (1975).
24	Tss	Sunnyside tuff (p. 2)-----	46.3±1.0	Sanidine------	Thunder Mtn. cauldron complex-	Leonard and Marvin (1982).
25	Tss	----------do-----------------	46.3±1.1	Sanidine------	----------------do-----------------------	Leonard and Marvin (1982).
			47.7±1.6	Biotite--------	----------------do-----------------------	Do.
26	Trb	Rhyolite of Red Butte (p. 13).	46.9±1.6	Biotite--------	Southern part of Van Horn Peak cauldron complex.	R.F. Marvin, written commun., 1980.
27	Tgp	Gray porphyry (p. 10)---	46.9±2.8	Hornblende-	----------------do-----------------------	R.F. Marvin, written commun., 1983.
			49.5±1.4	Biotite--------	----------------do-----------------------	Do.
28	Tem	Tuff of Eightmile Creek (p. 15).	47.5±1.3	Biotite--------	Custer graben------------------------	R.F. Marvin, written commun., 1984.
29	Ttm	Tuff of Table Mountain (p. 8).	47.8±1.7	Biotite--------	Corral Creek cauldron segment---	R.F. Marvin, written commun., 1982.
30	Th	Tuff of Herd Lake (p. 17).	48.1±1.7	Biotite--------	Southeastern part of quadrangle--	Do.
31	Tem	Tuff of Eightmile Creek (p. 13).	48.4±1.7	Biotite--------	Southern part of Van Horn Peak cauldron complex.	Do.
32	Te	Tuff of Ellis Creek (p. 8).	48.4±1.6	Biotite--------	Panther Creek graben---------------	Do.

Table 1. *Potassium-argon ages of the Eocene Challis Volcanic Group and intrusive rocks*--Continued

Locality No. on map	Map unit symbol	Map unit name (page number)	K-Ar age (m.y.)	Material dated	Sample locality	Sources of data (see list of references)
33	Trm	Rhyolite of Mill Creek Summit (p. 17).	48.5±1.2	Biotite--------	Southeastern part of quadrangle--	Marvin and Dobson (1979).
34	Tdf	Dacitic and rhyodacitic lava (p. 8).	48.6±1.7	Biotite--------	Panther Creek graben--------------	R.F. Marvin, written commun., 1980.
35	Tvs	Volcaniclastic and sedimentary rocks (p. 18).	49.0±1.8	Biotite--------	Southeastern part of quadrangle--	R.F. Marvin, written commun., 1982.
			49.0±2.9	Hornblende-	----------------do-----------------------	Do.
36	Tdf	Dacitic and rhyodacitic lava (p. 18).	49.2±1.2	Biotite--------	----------------do-----------------------	Marvin and Dobson (1979).
37	Tdf	----------do----------------	49.3±1.4	Plagioclase--	----------------do-----------------------	Armstrong (1975).
38	Tbal	Mafic lava (p. 18)--------	50.3±1.5	Whole rock--	----------------do-----------------------	Do.
39	Tdf	Dacitic and rhyodacitic lava (p. 14).	50.4±1.8	Biotite--------	Twin Peaks caldera area-----------	R.F. Marvin, written commun., 1982.
40	Tll	Lower latite lava (p. 4).	50.8±1.7	Sanidine------	Thunder Mtn. cauldron complex--	Leonard and Marvin (1982).
41	Tdf	Dacitic and rhyodacitic lava (p. 8).	51.1±1.8	Biotite--------	Northern part of Van Horn Peak cauldron complex.	R.F. Marvin, written commun., 1982.
42	Tdf	Dacitic and rhyodacitic lava (p. 18).	51.1±1.7	Biotite--------	Southeastern part of quadrangle--	McIntyre and others (1976).

*Not shown at this map scale.

Table 2. *Potassium-argon ages of Cretaceous granitic rocks of the Idaho batholith*

[All ages calculated using constants of Steiger and Jaeger (1977). Many of these potassium-argon ages do not represent ages of pluton emplacement. Many are younger because of prolonged residence of the rocks at temperatures above the argon blocking temperature and because of reheating associated with Eocene plutonism (see Criss and others, 1982); do, ditto]

Locality letter on map	Map unit symbol	Map unit name	K-Ar age (m.y.)	Material dated	Sample locality and comments	Sources of data (see list of references)
A	Klg	Leucocratic granite.	63.6±1.4	Biotite--------	Greenback Mine, southwest of Stanley.	R.F. Marvin, written commun., 1980.
B	Klg	----------do-----------	65.1±0.8	Biotite--------	Warm Spring Guard Station, southwest of Stanley.	R.J. Fleck, written commun., 1984.
C	Klg*	----------do-----------	70.3±2.5	Biotite--------	Northeast of Paddy Flat, near northwest corner of quadrangle.	R.F. Marvin, written commun., 1982.
D	Klg	----------do-----------	72.1±1.7	Biotite--------	Southeast of Landmark; dike (not shown on map).	R.F. Marvin, written commun., 1980.
E	Klg	----------do-----------	72.6±2.5	Biotite--------	Northeast of Landmark; dike (not shown on map).	Do.
F	Klg	----------do-----------	75.0±2.7	Muscovite----	Lost Packer Mine, near Casto; dike (not shown on map).	R.F. Marvin, written commun., 1985.
G	Kg	Muscovite-biotite granodiorite and granite.	65.3**	Biotite--------	Southeast of Deadwood Reservoir.	Criss and others (1982).
H	Kg	----------do-----------	66.2±0.9	Biotite--------	Northeast of Deadwood Reservoir.	R.J. Fleck, written commun., 1984).
			68.8±0.2	Muscovite----	-----------------do------------------	Do.
I	Kg	----------do-----------	68.0**	Biotite--------	Near southwest corner of quadrangle.	Criss and others (1982).

Table 2. *Potassium-argon ages of Cretaceous granitic rocks of the Idaho batholith*--Continued

Locality letter on map	Map unit symbol	Map unit name	K-Ar age (m.y.)	Material dated	Sample locality and comments	Sources of data (see list of references)
J	Kg	----------do----------	68.6**	Biotite--------	West of Deadwood Reservoir.	Do.
K	Kg	----------do----------	69.5±2.3	Biotite--------	West of Yellow Pine-----------	R.F. Marvin, written commun., 1974.
			70.7±2.3	Muscovite----	----------------do----------------	Do.
L	Kg	----------do----------	72.1±2.6	Biotite--------	West of Yellow Pine-----------	R.F. Marvin, written commun., 1982.
			72.2±1.7	Muscovite----	----------------do----------------	Do.
M	Kg	----------do----------	69.8±2.3	Biotite--------	West of Yellow Pine-----------	R.F. Marvin, written commun., 1974.
			74.1±1.7	Muscovite----	----------------do----------------	Do.
N	Kg	----------do----------	73.1±2.6	Biotite--------	East of Paddy Flat, near northwest corner of quadrangle.	R.F. Marvin, written commun., 1982.
			74.7±2.7	Muscovite----	----------------do----------------	Do.
O	Kg	----------do----------	73.9±2.7	Biotite--------	East of Warm Lake, in northwest part of quadrangle.	Do.
			75.8±2.7	Muscovite----	----------------do----------------	Do.
P	Kgd	Biotite granodiorite	61.5**	Biotite--------	South Fork Payette River, southwest of Stanley.	Criss and others (1982).
Q	Kgd	----------do----------	62.0**	Biotite--------	East of Lowman----------------	Do.
R	Kgd	----------do----------	62.4**	Biotite--------	West of Lowman----------------	Do.
S	Kgd	----------do----------	63.4**	Biotite--------	South Fork Payette River, northwest of Jackson Pk.	Do.

Table 2. *Potassium-argon ages of Cretaceous granitic rocks of the Idaho batholith*--Continued

Locality letter on map	Map unit symbol	Map unit name	K-Ar age (m.y.)	Material dated	Sample locality and comments	Sources of data (see list of references)
T	Kgd	----------do----------	68.5**	Biotite--------	South of Landmark--------------	Do.
U	Kgd	----------do----------	72.5**	Biotite--------	Northeast of Stanley------------	Do.
V	Kgd	----------do----------	72.7±2.6	Biotite--------	North of Warm Lake-----------	R.F. Marvin, written commun., 1982.
W	Kgd	----------do----------	73.0±2.5	Biotite--------	Gold Fork River, in northwest part of quadrangle.	R.F. Marvin, written commun., 1981.
X	Kgd	----------do----------	74.9±2.5	Biotite--------	East of Landmark---------------	R.F. Marvin, written commun., 1980.
Y	Kgd	----------do----------	76.3±2.6	Biotite--------	Northeast of Seafoam Ranger Station.	R.F. Marvin, written commun., 1981.
Z	Kgd	----------do----------	78.9±2.8	Biotite--------	Southwest of Eagle Nest Lookout, near west edge of quadrangle.	R.F. Marvin, written commun., 1982.
AA	Kgd	----------do----------	81±2	Biotite--------	North of Robinson Bar Ranch	Armstrong (1975).
BB	Kgd	----------do----------	81.3±2.9	Biotite--------	North of Sunbeam---------------	R.F. Marvin, written commun., 1985.
CC	Kgd	----------do----------	81±2	Biotite--------	Hw. 93, northeast of Stanley---	Armstrong (1975).
DD	Kgd	----------do----------	83.2±2.8	Biotite--------	White Cloud Stock, southeast of Stanley.	R.F. Marvin, written commun., 1981.
EE	Kgd	----------do----------	84.7±1.9	Biotite--------	White Cloud Stock; sample somewhat porphyritic.	Do.

Table 2. *Potassium-argon ages of Cretaceous granitic rocks of the Idaho batholith*--Continued

Locality letter on map	Map unit symbol	Map unit name	K-Ar age (m.y.)	Material dated	Sample locality and comments	Sources of data (see list of references)
FF	Kgd	----------do----------	85.6±2.1	Biotite--------	White Cloud Stock-------------	Marvin and Dobson (1979).
GG	Kgd	----------do----------	88.9±3.1	Biotite--------	Pat Hughes Stock, Thompson Creek.	Marvin and others (1973).
HH	Kgd	----------do----------	96.9±3	Biotite--------	Northeast of Robinson Bar Ranch.	Armstrong (1975).
II	Kgd	----------do----------	98.1±3.3	Biotite--------	Juliette Stock, west of Bayhorse.	McIntyre and others (1976).
JJ	Kgdp	Porphyritic biotite granodiorite and granite.	62.6**	Biotite--------	Northwest of Stanley-----------	Criss and others (1982).
KK	Kgdp	----------do----------	77.9±2.8	Biotite--------	South of Yellow Pine-----------	R.F. Marvin, written commun., 1985.
LL	Kgdp	----------do----------	79.8±2.7	Biotite--------	West of Sunbeam---------------	R.F. Marvin, written commun., 1980.
			84.7±2.9	Hornblende--	----------------do----------------	Do.
MM	Kgdp	----------do----------	84±2	Biotite--------	West of Sunbeam---------------	Armstrong (1975).
NN	Kt	Tonalite and granodiorite.	71.9±2.5	Biotite--------	North of Paddy Flat, near northwest corner of quadrangle.	R.F. Marvin, written commun., 1974.
OO	Kt	----------do----------	81.2±2.9	Biotite--------	Southeast of Stanley; unmapped patch of Kt in Kgdp.	R.F. Marvin, written commun., 1985.
PP	Kt	----------do----------	81.6±2.9	Biotite--------	Gold Fork River, near west edge of quadrangle.	R.F. Marvin, written commun., 1982.

*Not shown at this map scale.
**No value for standard error provided by Criss and others (1982).

Table 3. *^{40}Ar-^{39}Ar age determinations on sanidine, tuff of Challis Creek, Challis Volcanic Group*

[L. W. Snee, written commun., 1984]

Locality letter on map	Map unit symbol (page number)	Map unit name	Age (m.y.)
C1	Tcru (p. 11)	Tuff of Challis Creek, upper unit-----	45.5±0.3
C2	Tcrl (p. 12)	Tuff of Challis Creek, lower unit-----	45.8 ±0.2
C3	Tcrm* (p. 12)	Tuff of Challis Creek, middle unit----	45.9 ±0.2
C4	Tcr* (p. 12)	Tuff of Challis Creek, outflow unit---	46.3 ±0.2
C5	Tcrl* (p. 12)	Tuff of Challis Creek, lower unit-----	46.5 ±0.1

*Rock matrix is zeolitized.

Table 4. *Summary of cauldron-related volcanic events, Eocene Challis Volcanic Group, Challis quadrangle*

[Leaders (---), no data]

Subsidence feature	Tuff eruption that triggered subsidence (page number)	Time of initial subsidence (m.y.)
Corral Creek cauldron segment.	Lithic tuff of Corral Creek (p. 9)-	---
Van Horn Peak cauldron complex.	Tuff of Ellis Creek (p. 8)-----------	48.4
Custer graben and part of Van Horn Peak cauldron complex.	Tuff of Eightmile Creek (p. 15)---	47.5
Thunder Mountain cauldron complex.	Dime- and quarter-size lapilli tuff (p. 4).	---
Castle Rock cauldron segment.	Quartz-biotite tuff (p. 6)------------	---
Twin Peaks caldera----	Tuff of Challis Creek (p. 11)-------	46.5

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