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Abstracts of the Symposium on the Geology and Mineral Deposits of the Challis $1^{\circ} \times 2^{\circ}$ quadrangle, Idaho

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Compiled by

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

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INTRODUCTION

The symposium on the geology and mineral deposits of the Challis $1^{\circ} \times 2^{\circ}$ quadrangle is the seventh public meeting in which the results of studies made under the Conterminous United States Mineral Assessment Program (CUSMAP) have been discussed. CUSMAP was initiated in 1977 to provide an up-to-date assessment of the mineral potential of the lower 48 states. Under CUSMAP, more than 66,000 square miles in 12 states have been assessed to date, and additional assessments will be completed on another 60,000 square miles in the near future.

One of the major objectives of CUSMAP is the development and application of new concepts for the identification of mineral resource potential in heretofore untested but possibly mineralized areas. CUSMAP is providing new information on present and potential mineral supplies and is producing important data to guide our national minerals policy, for minerals exploration, and for land-use planning by Federal, State, and local governments. The results of the CUSMAP assessments are published in folio format. In addition to a mineral resource appraisal report and map, a folio may include geologic, geochemical, geophysical, and other maps and reports. A summary report for each quadrangle is published as a U.S. Geological Survey Circular. Basic data developed during the studies are published in a wide range of other technical reports.

The Challis CUSMAP project began in 1979. At that time modern geologic mapping was available for 15 percent of the quadrangle. Major emphasis, therefore, was placed on improvement of the geologic data base, a necessary prerequisite to a meaningful mineral resource appraisal. A wide range of geologic settings is present; 41 mineral commodities have been produced or occur in anomalous but subeconomic quantities. The abstracts in this report are summaries of parts of the work done on the Challis project to date.

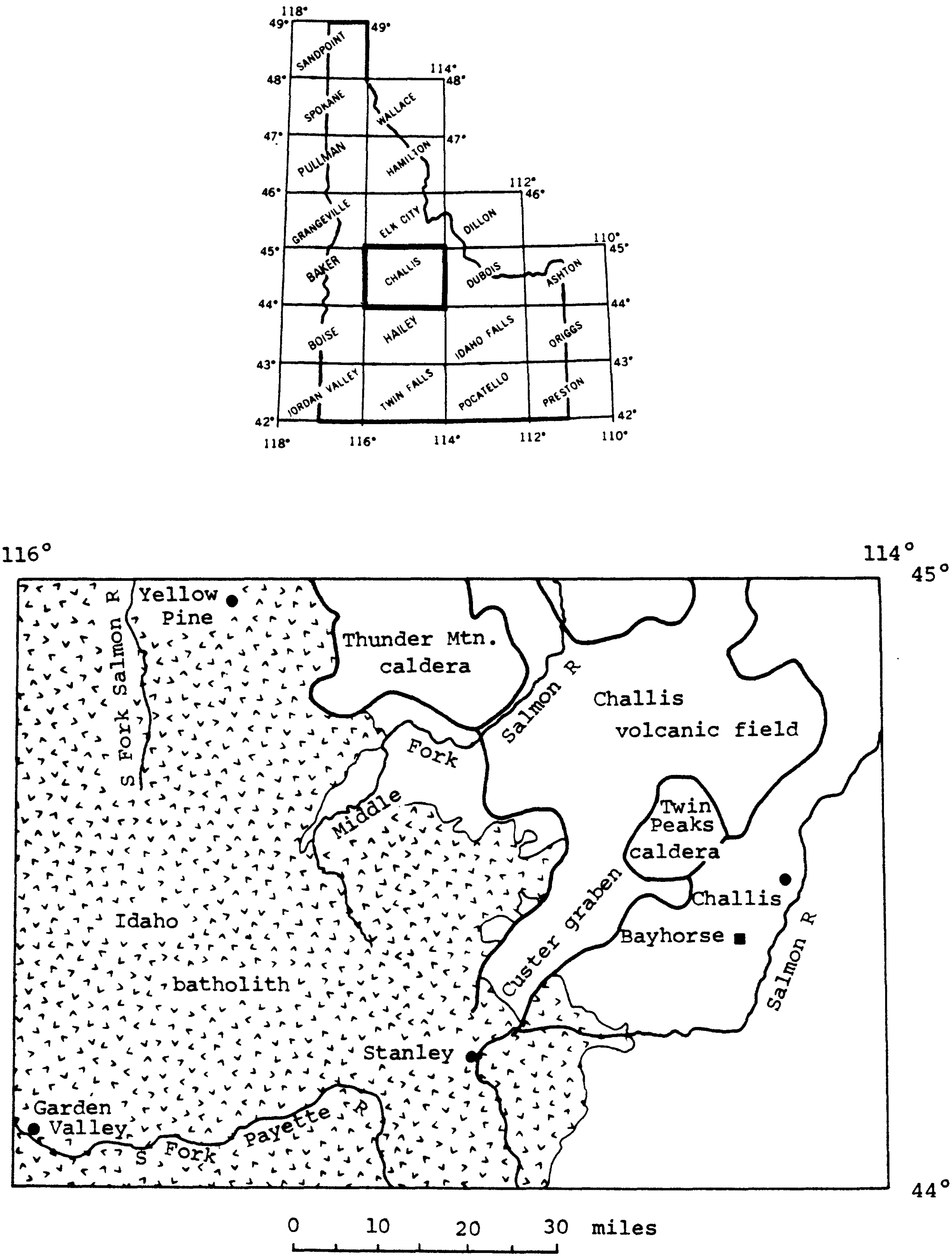

Figure 1. Maps showing location of Challis 1° x 2° quadrangle and selected geologic features and towns within the quadrangle.

THE PHILOSOPHY OF MINERAL RESOURCE APPRAISAL - CHALLIS 1^{o} x 2^{o} CUSMAP - MODELS, ANALOGY, AND METAPHOR

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Modeling of ore deposits and other geological phenomena is a common practice, yet seldom do we examine the underlying thought processes used in constructing our models. Models are sets of elements, both data and processes, drawn from the universe. The models so constructed differ from reality in three ways: by deletion, by distortion, and by generalization. A deletion process is necessary because the number of elements available in the universe for our models is overwhelming. Distortion occurs because of inferences we use to describe data, and because of bias resulting from our own personal experience. Individuals trained in one school of thought will tend to delete and distort data to favor their own experience. Generalization is a process by which a model of a given ore deposit comes to represent an entire category of deposits allowing us to recognize deposits we have never seen before. To develop new ore deposit models and critically examine existing models, it is fruitful to ask what has been deleted, distorted, and generalized, and how a particular model would differ with changes in those aspects.

Analogy is a process by which we extend our models into new physical and conceptual territory. Analogy by metaphor is an extremely powerful tool for both the explorationist and the theorist. Metaphor is useful for introducing new terminology and concepts into geologic theory; for providing a nondefinitional mode of reference useful for working with uncertain products and processes; for explaining concepts and ideas to non-geologists; for aiding thought processes by consolidating information; and, finally, by focusing attention on new combinations of fact and process, metaphor aids in increasing our perception of features in the universe and frees us from prejudice developed through our own experience.

Awareness of the basic aspects of models, analogy, and metaphor and their interrelations allows examination of some of the thought processes involved in the description of known deposits and the search for new mineral resources. Lack of understanding of these aspects can lead to mental traps and stifle the innovation needed to see ore where others see only barren rock.

CRETACEOUS ROCKS OF THE ATLANTA LOBE OF THE IDAHO BATHOLITH

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Rocks comprising the Atlanta lobe of the Idaho batholith, in the western part of the Challis 1^{o} x 2^{o} quadrangle, include tonalite, hornblende-biotite granodiorite, porphyritic granodiorite, biotite granodiorite, muscovite-biotite granite, and leucocratic granite. The six rock types are believed to have been emplaced during at least three periods of magmatic intrusion and to range from about 90 to 72 m.y. in age.

Tonalite is the oldest rock type and it crops out near the western and eastern margins of the batholith. Closely associated with the tonalite are hornblende-biotite granodiorite and porphyritic granodiorite, the latter being characterized by unusually large phenocrysts of potassium feldspar. Biotite granodiorite is younger and is the most common rock and is widely exposed. Muscovite-biotite granite forms the core of the Atlanta lobe and is mineralogically similar to the leucocratic granite, which is younger than the biotite granodiorite.

The Cretaceous igneous rocks are intensively faulted, intruded by numerous Tertiary dikes, and altered locally by plutonic rocks of Tertiary age. Principal fault patterns strike north, northwest, and northeast. Northwest faults terminate against a major set of northeast-trending faults that extends across the batholith and probably across the quadrangle and beyond.

There are only two known mineral deposits of significant size in the granitic rocks that appear to be genetically related to Cretaceous plutonism, both of which are molybdenum deposits in the eastern part of the area.

THE CHALLIS VOLCANIC FIELD

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The Challis volcanic field comprises remnants of a vast field of tuffs and lavas of Eocene age that possibly were originally contiguous with Eocene fields in adjacent states. Volcanism started about 51 m.y. ago with eruptions of lavas of dominantly dacite composition from a variety of widely separated vents. Caldera-forming eruptions started in the extreme northeastern part of the quadrangle and then moved westward and southward. Linear, rather than arcuate boundaries of the earliest cauldrons as well as of later cauldrons, indicates strong control by pre-existing northeast-trending faults.

Major collapse of the central part of the Van Horn Peak complex in the eastern Challis 1^{o} x 2^{o} quadrangle occurred about 48.5 m.y. ago with the eruption of the rhyodacite tuff of Ellis Creek. The Ellis is as thick as 200 m where preserved as outflow and as thick as 1000 m where preserved within the cauldron complex. The Ellis-related caldera extended into the north-central Challis quadrangle to straddle part of the area now occupied by the Eocene Casto granite and the Thunder Mountain volcanic center. Following the Ellis volcanism, however, the Thunder Mountain complex on the northwest and the Van Horn Peak complex on the southeast operated as two independent centers, perhaps as the result of the evolution of two separate cupolas of the rising Casto granite.

Ash-flow tuff eruptions in both the Thunder Mountain and Van Horn Peak areas culminated in the eruption of strikingly similar, alkali-feldspar rich tuff-Sunnyside Rhyolite of Thunder Mountain, and the tuff of Challis Creek at Twin Peaks.

PRE-TERTIARY SEDIMENTARY TERRANES OF THE BAYHORSE AREA--CHALLIS 1^{o} x 2^{o} QUADRANGLE

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Limited outcrops of pre-Tertiary sediments of Proterozoic to Permian age are exposed mainly in the eastern half of the Challis 1^{o} x 2^{o} quadrangle, extend south into the Wood River region, and provide the only information on the early sedimentary history and structural complexity of this great stack of allochthonous terranes. These rocks indicate a long and varied sedimentary record during the Proterozoic and Paleozoic; regional folding and faulting in the Cambrian and Ordovician was followed by extensive early Mesozoic folding, extensive west to east thrust faulting in the middle and late Mesozoic, and late Mesozoic normal faulting. The Idaho Batholith intruded and engulfed the allochthonous sedimentary sequences in mid-to-late Cretaceous and in the Eocene, and the Challis volcanics blanketed the region in Eocene time.

The Bayhorse region includes six fault-bounded structural-stratigraphic terranes, each of which is made up of a sedimentary sequence that differs significantly from those of adjacent terranes. Four of the six terranes include stratigraphic units older than middle Ordovician that have not been definitely correlated beyond the Bayhorse exposures, but middle Ordovician and younger units of three terranes are widespread far to the east and south.

The physical properties, stratigraphic succession, and composition of the rocks in each terrane have profoundly influenced the origin and localization of ore deposits. The Salmon River lineament separates two of the terranes, and may have regional significance on the distribution of mineralization.

GEOPHYSICAL STUDIES IN THE CHALLIS $1^{\circ} \times 2^{\circ}$ QUADRANGLE, IDAHO

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Regional gravity and aeromagnetic surveys have been made in the Challis $1^{\circ} \times 2^{\circ}$ quadrangle and a study has been made of the seismicity of the eastern part. The gravity and magnetic coverage provide a section across the Idaho batholith extending into the basin and range structure to the east. The seismic study covers the area of most intense seismicity in central Idaho. The regional Bouguer gravity anomaly shows an inverse correlation with regional topography. Superimposed on the large regional gravity low centered over the central part of the quadrangle are local anomalies reflecting lithology and structure. Gravity lows produced by low-density rocks within structural depressions define the major calderas and valleys. A large gravity high coincident with the Bayhorse anticline suggests that the anticline reflects a basement high. A regional magnetic low overlies the central zone of the Idaho batholith with local magnetic highs produced by Tertiary intrusions within the batholith. Magnetic highs are produced by the border phases of the batholith and by Cretaceous and Tertiary plutons east of the batholith. Tertiary volcanic rocks produce both magnetic highs and lows depending on the direction of the remanent magnetization. The most prominent of several lineaments defined by the gravity and magnetic data extends northeast parallel to the eastern Snake River Plain and forms the southeastern boundary of the Van Horn Peak caldera complex. The seismicity is concentrated in a zone parallel to and northwest of this lineament.

TERTIARY PLUTONS IN CENTRAL IDAHO

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The Tertiary plutonic rocks in the Challis 2° map area consist of a bimodal group of mineralogically and chemically distinct, 42-45 m.y. old epizonal granite plutons and 46-50 m.y. old diorite complexes. Both groups are best exposed in the eastern two-thirds of the area. Each of the plutonic units has associated hypabyssal intrusive equivalents that collectively form the Idaho porphyry belt and other dike swarms. Map patterns and similarity of rock types suggest that each of the hypabyssal units probably has volcanic equivalents that are part of the Challis volcanic field.

The Tertiary plutons are exposed in the south-central map area in a series of rhomboid-shaped fault blocks formed by the intersection of major northwest-trending and northeast-trending faults. The northwest faults form a series of horsts and grabens. Erosion of horst blocks has exposed the Tertiary plutons; grabens contain older plutonic rocks of the Idaho batholith that host Tertiary mineralization. Many of the intrusive rocks in the north-central and eastern map areas are in structures formed by major northeast faults that sharply truncate the northwest-trending horst and graben province to the south. The Panther Creek and Custer grabens are part of one of these northeast structures that extend across Idaho and possibly Montana. The northeast structures are complicated by regional uplift that has been more rapid in the western part of the batholith where massive plutonic rocks forming the core of the Atlanta lobe are exposed.

The Tertiary granite plutons and diorite complexes are generally found close to each other. These rocks have many of the characteristics of anorogenic (R or A type) granites and are probably genetically related to intracontinental rifting.

GEOCHEMICAL STUDIES IN THE CHALLIS $1^{\circ} \times 2^{\circ}$ QUADRANGLE

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Geochemical studies in the Challis quadrangle focus on the use of trace element analyses of bedrock and stream sediments for characterizing the chemical features of the area and for prospecting. This presentation is devoted to an explanation of the use and value, including limitations, of stream sediment geochemistry in the Challis study.

Stream sediments provide an inventory of the rocks, minerals, and chemistry of a watershed. Their chemical analysis serves to identify unusual concentrations of elements generally found only in trace or minor amounts. They provide evidence of rock bodies, little or not at all exposed because of small size, great susceptibility to weathering, or because of climate and plant cover. Furthermore, they contain the material evidence for tracking down the sources of such contained detritus as ore minerals. The data are useful for identifying and locating bedrock terranes of possible interest and for inspiring and guiding further research. Interpretations of stream sediment geochemistry are in the mind of the beholder and remain uncertain until or unless tested by additional studies.

THE TWIN PEAKS CALDERA AND ASSOCIATED ORE DEPOSITS

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The Twin Peaks caldera, a 20 km by 14 km collapse structure, formed about 47-45 m.y. ago with the eruption of approximately 320 km^3 of alkali-rhyolite ash-flow tuff. The ash-flow deposits, the tuff of Challis Creek, form two thick intracaldera cooling units separated by relatively thin ash-flow tuff and epiclastic sediments. Total intracaldera thickness of these tuffs is at least 800 m. The tuff of Challis Creek occurs as erosional remnants as far as

40 km from the caldera; these distant remnants rarely exceed 75 m in thickness. Subsequent to these major eruptions the northern half of the caldera experienced further subsidence with additional ash-flow volcanism. Renewed collapse of the northern half of the infilled caldera split the structure along a northeast-trending medial fault along which additional magma was explosively erupted. Collapse of this segment of the caldera was probably piecemeal and catastrophic, leaving a high topographic caldera wall and medial scarp. Collapse of the unsupported caldera wall, concomitant with ash-flow eruption, produced a megabreccia deposit intermixed with ash-flow tuff. The megabreccia deposit is exposed over an area of approximately 29 km^2 and contains an estimated 24 km^3 of material ranging from bedded talus deposits to unsorted block avalanche debris containing blocks as much as 65 m in length.

Post-collapse rhyolite intrusives pervade the northern margin of the caldera and form linear dikes within the complex northern half. Hydrothermal alteration is spatially associated with some of these intrusives. Hydrothermally altered tuffs and strongly silicified breccia, intruded by altered rhyolite, host gold-silver mineral deposits at the Parker Mine, located on the west margin of the caldera. Geologic relationships similar to those at the Parker Mine exist elsewhere along the northern ring fracture of the caldera. In addition to precious metal occurrences, extensive areas of zeolitized ash-flow tuff and megabreccia occur along the northeast-trending medial fracture through the caldera. The zone of zeolitized rock extends for approximately 12,000 m along strike and is at least 1,000 m wide.

The complex northern half of the Twin Peaks caldera failed along structures, now mostly buried, into which post-collapse rhyolites were emplaced, and provided the most favorably prepared ground for the circulation of hydrothermal fluids. This area of the caldera offers the greatest potential for undiscovered mineral deposits.

ORE DEPOSITS RELATED TO THE THUNDER MOUNTAIN CALDERA COMPLEX

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Mined deposits of gold, silver, mercury, antimony, and tungsten are structurally related to subsidence of the Eocene caldera complex and to superposed regional strain shown by north-striking right-lateral shear zones and northeast-striking extension fractures. Gold deposits of the Thunder Mountain district are in the pyroclastic and volcaniclastic filling of Challis Volcanics in the central, youngest caldera. All other mined deposits are outside the youngest caldera, within or close to silicified zones that cut plutonic and metamorphic rocks of the Idaho massif. The extra-caldera deposits are near the intersection of discontinuous ring and radial fractures of the subsided complex. Ring fractures at 1/3, 1/2, 2/3, 5/6, and 6/6 of the 30-km radius of the cauldron (superstructure bounding the caldera complex) are favored by the extra-caldera deposits, most of which are xenothermal, virtually lacking in regional zoning of metals, and derived from metal sources only broadly referable to Tertiary magmatic processes. The distribution of many prospects fits the hypothesis that relates extra-caldera mined deposits primarily to large subsidence structures and superposed shear zones. Though cauldron subsidence (effective ~47 m.y. ago) and regional strain (superposed ~44 m.y. ago) are datable events, and though extensive silicification is by inference not older than ~44 m.y., the age of metallization remains uncertain. Interpretation of the Eocene structures and the mineral deposits within them is further complicated by widespread block faulting that has affected rocks of Miocene and Holocene age. Despite these uncertainties and complexities, the relations of large structures of Eocene age, together with local patterns of wallrock alteration, help narrow the search for concealed ore deposits related to the caldera complex.

EPITHERMAL GOLD-SILVER MINERALIZATION RELATED TO VOLCANIC SUBSIDENCE IN THE CUSTER GRABEN, CUSTER COUNTY, IDAHO

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The Custer graben is a 13 by 32 km northeast-trending volcanotectonic graben in the Challis volcanic field in central Idaho. The Yankee Fork mining district, which includes about half the graben, has produced in excess of $12,000,000 in gold, silver, copper, lead, and zinc since the early 1880s.

Four major rock types are present within the graben: Paleozoic sedimentary rocks and Tertiary andesites, pyroclastic rocks, and rhyolites. Graben subsidence began about 48 m.y. ago with the eruption of the tuff of Eightmile Creek. Hydrothermal alteration and epithermal mineralization took place about 44 m.y. ago in parts of the graben where there was both silicic intrusive activity and persistent fault movement. Pleistocene erosion and redeposition formed the large placer deposits of the Yankee Fork and Jordan Creek.

Both andesites and rhyolites host vein and disseminated mineral deposits. Ores are localized along a small number of discrete northeast- and northwest-trending fracture zones. Hypogene alteration consisted of pervasive propylitization and silicification followed by less extensive oxidation. Ore minerals are electrum, native gold and silver, chalcopyrite, and various sulfosalts in a gangue of pyrite and fine-grained quartz.

Volcanotectonic subsidence features are good exploration targets because young high-level mineral deposits are preserved in this environment. The Custer graben was an important host for epithermal mineral deposits because it had a favorable combination of source rocks, hydrothermal fluids, and suitably permeable host rocks. The processes that formed the mineral deposits were genetically related to structural and intrusive events accompanying development of the graben.

CONTROLS AND CHARACTERISTICS OF MINERALIZATION IN MIDDLE AND UPPER PALEOZOIC ROCKS IN CENTRAL IDAHO

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A belt of allochthonous, highly mineralized, black, siliceous-facies sedimentary rocks of Ordovician through Permian age crops out on the east side of the Idaho batholith, central Idaho. The value of past production of metals from this belt is $65 million; a conservative estimate of the total known resources is $6 billion. The most intensely mineralized zones are in black argillite and micritic limestone beds in Milligen Formation (Devonian) and Salmon River sequence (Mississippian?) below regional thrust faults near biotite granodiorite stocks of Cretaceous age.

Mineral resources include: (1) many high-grade lead-silver-zinc vein deposits; (2) an area containing tin mineralization associated with lead-silver deposits in the Galena District and Boulder Basin; (3) skarn tungsten veins; (4) two large molybdenum porphyries; and (5) stratabound deposits of zinc, barite, vanadium, and possibly lead and silver. As much as 6 percent tin occurs in ore at Boulder Basin in a mineralogical and chemical assemblage (Pb-Zn-Sb-Ag-Au-Se) similar to Bolivian-type tin deposits. These deposits occur in limy sandstones of Pennsylvanian-Permian Wood River Formation near Eocene hypabyssal intrusive bodies; all other lead-silver vein deposits are in black argillite sequences near Cretaceous stocks. It is now recognized that not only are the black shales host and probably sources of metals for the vein deposits, but that some of the productive deposits are stratabound and are probably syngenetic. Recent activity has been concentrated on exploration for the stratabound deposits and on the development and bringing into production of the Thompson Creek molybdenum deposit.

STRUCTURAL AND STRATIGRAPHIC CONTROLS OF ORE DEPOSITS IN THE BAYHORSE REGION, CUSTER COUNTY, IDAHO

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Major mineral commodities of the Bayhorse region include lead, zinc, silver, gold, molybdenum, tungsten, and fluorspar. Mineral commodities of unknown future potential include tin, vanadium, uranium, and barite.

Three factors dominate the positioning of ore deposits in this region: (1) sedimentary rock sections--their depositional history, composition, physical characteristics, and general geochemistry; (2) structural evolution of the area, and the resulting pattern of folds and faults; and (3) associated intrusive rocks that supply some elements, but mainly supply energy to mobilize hydrothermal fluids throughout the stratigraphic section.

Deposition of most of the fluorite and some of the lead-zinc-silver occurrences that flank the Bayhorse anticline are largely controlled by an extensive zone of solution, brecciation, and collapse structures, a paleokarst developed beneath an ancient erosion surface cut on Bayhorse Dolomite, and now capped by the impervious Ramshorn Slate. Steep faults that intersect this zone fed ore solutions from some subjacent source into a porous, reactive environment of deposition. Similar steep faults that cut other carbonate units at the Clayton Silver Mine and on Squaw Creek also have been channels for replacement ore bodies of considerable size. At the Ramshorn and Skylark Mines, similar steep faults in the Ramshorn Slate localize sulfide-bearing quartz-siderite veins that are controlled both by the fault zone and possibly by bedding.

Intrusive rocks serve both as the source of mineralizing solutions in contact metamorphic aureoles and, more significantly, as the source of energy to circulate connate and meteoric waters that mobilize sparse syngenetic metals and carry them to favorable sites of deposition.

A CASE FOR PLANTS IN EXPLORATION--GOLD IN DOUGLAS-FIR AT THE RED MOUNTAIN STOCKWORK, YELLOW PINE DISTRICT, IDAHO

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Evidence from this study indicates the presence of exploration targets beyond the stockwork not only for concealed deposits of Au and Mo, but also for W and Sn. The targets are new and, to a considerable degree, unexpected from other surface evidence. The biogeochemical anomalies that help define the targets are extensive, and the deposits that might be sought are presumably of low grade.

Red Mountain, which lies on the western edge of the ring-fracture zone of the Eocene Quartz Creek cauldron, has been prospected for Au and Ag for at least 50 years. A biogeochemical study was conducted in 1980-82 in an attempt to better assess the mineral potential of the stockwork area. Bedrock contacts are concealed by colluvium, glacial deposits, and forest cover. Soil and plant samples were collected on 200 m centers over an area of 1100 m x 2500 m. The wood of douglas-fir (*Pseudotsuga menziesii*) and the leaves of beargrass (*Xerophyllum tenax*) were used because they concentrate Au and Mo, respectively. Results of the metal content in soil were trivial, although they did indicate a W anomaly south of the stockwork. Analysis of ashed wood by instrumental neutron activation yielded Au values of 0.07-14.2 ppm and revealed two distinct Au populations. More importantly, the highly anomalous samples (>4 ppm) are concentrated in the southern quarter of the grid in an area that has no anomalous Au in the sampled soils, has not been prospected, and lies within inclusion-bearing granodiorite, not stockwork. Beargrass samples, which typically contain 20 ppm Mo, contained <5 to >500 ppm. A belt of above-median values of Mo transects some part of every map unit except the quartz body at the summit. The great extent and the continuity of this belt require some comparably extensive bedrock source of the Mo. The location, shape, and Mo content of the bedrock source remain conjectural, but the source must be large. Subsequent geomagnetic traverses confirmed the belt configuration.

MINERAL DEPOSITS IN THE SOUTHERN PARTS OF THE ATLANTA LOBE OF THE IDAHO BATHOLITH AND THEIR RELATIONSHIP TO TERTIARY INTRUSIVE ROCKS AND FAULTING

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Most mineral deposits in the Atlanta lobe of the Idaho batholith are genetically related to Tertiary intrusive rocks; regional faults have controlled location of the deposits. Pink granite of the Sawtooth batholith, about 44 m.y. old, contains more beryllium, uranium, fluorine, and molybdenum than does rock of the intruded Idaho batholith. Gold-silver vein deposits along the western side of the Sawtooth batholith are concentrated in hydrothermally altered rocks of the Idaho batholith on the downthrown side of the Montezuma fault. Many of the veins follow or crosscut Tertiary dikes.

Pink granite of the Sawtooth batholith and nearby 47-m.y.-old dioritic rocks crop out in the Ten Mile RARE II area, as do swarms of associated dikes. Geochemical sampling shows silver, gold, and molybdenum to be concentrated near the intrusive Tertiary rocks along northwest-trending faults that cross the area.

A major northeast-trending fault system controls the location of vein deposits in the Boise Basin. Tertiary plutonic rocks and dikes have intruded along the faults and the veins cut both the Tertiary plutonic rocks and the dikes. Two molybdenum deposits in the area occur in and along rhyolitic dikes, and a fission-track date from zircon taken from rhyolite at one of the deposits gives a date of 29.3±1.7 m.y. Veinlets containing molybdenite cut the rhyolite and must be younger. The mineralization probably relates to waning phases of the Tertiary plutonic activity. Mineralized deposits in Tertiary rocks also occur along northeast-trending faults and grabens in the northeast part of the Challis quadrangle.

MINERALIZATION AND RHYOLITE INTRUSIONS IN THE CHALLIS VOLCANIC FIELD

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Gold-silver deposits within the Challis volcanic field are associated with rhyolitic rocks that are spatially related to a belt of northeast-trending faults that extends across the Challis $1^{\circ} \times 2^{\circ}$ quadrangle. Aphyric to porphyritic rhyolites, predominantly of intrusive origin, occur as small plugs, eroded domes, linear dikes, and one large stock-sized multiple intrusive complex. These rocks are exposed throughout the Custer graben and the Van Horn Peak cauldron complex and postdate the ash-flow tuffs erupted from the cauldron complex. Intrusion of rhyolite magma occurred along pre-existing northeast-trending structures and along caldera ring fractures. Post-emplacement faulting has displaced some of the rhyolites. Rhyolite bodies are massive to steeply flow laminated and locally display varied breccia textures. Autobrecciated rhyolite and pebble dikes occur as isolated irregular to pipe-like bodies within massive or flow-laminated rhyolite.

The intrusive rhyolites are interpreted to be high-level rhyolites emplaced near the surface of the crust. Locally, viscous rhyolite magma apparently breached the surface as extrusive domal masses.

Epithermal precious-metal deposits are spatially associated with some of the high-level rhyolites exposed in the Custer graben and in the Panther Creek graben at the northeast end of the rhyolite belt. Hydrothermally altered rocks spatially associated with intrusive rhyolites also exist within the Van Horn Peak cauldron complex and are favorable areas for exploration for epithermal precious metals.

LEAD ISOTOPE CHARACTERISTICS OF ORE SYSTEMS IN CENTRAL IDAHO

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About 60 new lead-isotope analyses were made on ore minerals, igneous rocks, and shales to test the use of lead isotopes in mineral prospect evaluation of Cretaceous and Tertiary magmatothermal deposits of central Idaho. The lead-isotope pattern is complex but separable into two groups: Group A has many values of $^{206}Pb/^{204}Pb \leq 18.0$ but has a continuum of values to exceed 21, whereas Group B always has values of ≥ 18.5 and most values are between 19 and

20. For Group A and Group B samples that have similar values of $^{206}Pb/^{204}Pb$, Group A always has values of $^{208}Pb/^{204}Pb$ greater than Group B. "Tin granites" can also be in either Group A or B and cannot be distinguished from molybdenum deposits by lead isotope ratios. Group A data are similar to those from the Rocky Mountains; Group B resemble those from the Great Basin. Large molybdenum deposits generally have lower values of $^{206}Pb/^{204}Pb$ but are found in both isotopic groupings (e.g., Group A--Thompson Creek; Group B--White Cloud). The Clayton Silver mine--the largest silver deposit in Idaho outside the Coeur d'Alene district--also is in Group A, but has a $^{206}Pb/^{204}Pb$ in the range between 18 and 19.

Group B leads are found in a "horn-shaped" band opening to the east along the boundary between the Challis and Hailey $1^{\circ} \times 2^{\circ}$ sheets. Where gravity is not dominated by volcanics, Group A galenas are in areas of positive gravity anomalies, signifying relatively shallow Precambrian crystalline basement. Their lead-isotope apparent age is 1,620±100 m.y. Positive gravity anomalies are missing from the Group B area so that crystalline basement is deep or absent. The primary source of these leads seems not to be the shallow Paleozoic or Belt Supergroup rocks but rather a source more like material deep in the Great Basin.

LIGHT-STABLE ISOTOPE CHARACTERISTICS OF ORE SYSTEMS IN CENTRAL IDAHO

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We have investigated light stable isotopes in mineralized rocks and their hosts to place constraints on the sources of water and sulfur in hydrothermal systems of central Idaho. Analyses of inclusion fluids extracted from crushed sulfide and gangue minerals from Cretaceous porphyry and vein deposits give δD values of -130±25 per mil, indicating the involvement of meteoric waters. Meteoric waters, which continued to dominate hydrothermal systems around Tertiary plutons within the Idaho batholith, created zones extremely depleted in D and ^{18}O over areas > 15,000 km^2 through water-rock interactions. The $\delta^{34}S$ values of sulfides from most of the Cretaceous and Tertiary deposits are quite high, generally from +4 to +13 per mil; several samples from deposits considered to be of syngenetic or remobilized-syngenetic origin have $\delta^{34}S$ values as high as +23 per mil. A correlation between commodity and sulfur-isotopic composition is absent; there are relatively ^{34}S-enriched Mo (Thompson Creek) and Pb-Zn-Ag (Ramshorn) deposits, and relatively ^{34}S-depleted Mo (Little Boulder Creek) and Pb-Zn-Ag (Dryden) deposits. Deposits hosted by black shale, however, generally have $\delta^{34}S$ values higher than those hosted by carbonate and quartzite, or by granite. Although many of the districts are isotopically inhomogeneous, individual deposits commonly have tightly clustered sulfur-isotopic compositions.

These isotopic data support a model in which meteoric water, set in convective circulation by granitic intrusions, leached sulfur from crustal sources, such as syngenetic-diagenetic sulfides in sedimentary rocks, evaporites, or pre-Cretaceous sulfide deposits. This sulfur then mixed in varying proportions with sulfur from the reservoirs of adjacent plutons.

DEPOSITIONAL CONTROLS OF TUNGSTEN IN CENTRAL IDAHO

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Skarn and breccia fill deposits have potential for small mining activity in the central Idaho. The skarns are found in contact with Cretaceous intrusives, with scheelite and ferberite as the major tungsten minerals. Most often the intrusive at the contact has K-feldspar megacrysts (1-3 cm) and veining of K-feldspar and quartz. These metasomatized portions of the intrusives are associated with the higher grade zones within the skarn. Skarns in the south-central portion of the quadrangle are all found stratigraphically just below thrust faults mapped by Hall and Hobbs (1983) that may be Sevier in age. These skarns are in argillaceous zones of the Paleozoic metasediments. Precambrian metasediments host the skarns in the northwest part of the quadrangle. The breccia deposits are found at the intersection of a series of N5°E regional shear zones and local faults trending about N30°E. Within the shear zones the batholith has a bleached appearance, becomes finer grained from the multistaged influx of silica, and contains large vugs in extensional fractures and smaller vugs where feldspar minerals have been leached. Several stages of quartz veins carry scheelite and shreds of sericite. The breccia fragments are generally silicified Idaho batholith, clast size varies, and they are not sorted. The shape of the deposits is controlled by faulting. There is some evidence in these deposits of early disseminated arsenopyrite (with gold), a later stage of quartz-scheelite veining, and a late stage phase of stibnite (with silver) veining. The tungsten could have been remobilized from nearby skarn areas and carried along regional fractures.

COBALT IN PRECAMBRIAN ROCKS OF CENTRAL IDAHO

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The Blackbird/"Idaho Cobalt Belt" trend of cobalt-copper mineralization in the Middle Proterozoic Yellowjacket Formation extends southeastward into the Challis 1° x 2° quadrangle. The major locus of mineralization crosses the North Fork of Iron Creek, where there is pyrite-chalcopyrite at the "Little No-Name" mine, pyrite-arsenopyrite to the north, and magnetite-pyrite-chalcopyrite to the south near Jackass Creek. Cobalt (overall 0.01-0.50 wt.% Co) is contained in pyrite and arsenopyrite. The deposits are grossly stratabound within northeast-dipping greenschist facies biotite-sericite-chlorite argillaceous quartzites and sandy argillites. Sparse mafic dikes and tuffs are present and black, fine-grained quartz-tourmaline (Fe:Mg~2:1) veins and breccias occur sporadically. None of the igneous rocks and veins are directly associated with ore. Specular hematite veins occur locally; one hematite deposit west of Moyer Creek lies at the base of a sequence of calcareous (now amphibole-scapolite-epidote) beds. To the east near Rattlesnake Creek, the Twin Peaks lead-copper deposit (only 5-10 ppm Co) may represent metals remobilized during metamorphism.

The Co-Cu-Fe deposits are best interpreted as distal-volcanogenic, sea-floor exhalative deposits. An unresolved question is whether the metals were vented into seawater and precipitated along with the clastic sediments, or whether partly or fully consolidated sediments were mineralized by upward-moving fluids. The magnetite-rich strata appear to represent a distal, partly oxidized, exhalative iron formation equivalent of the sulfide-arsenide deposits. No reason is yet clear for the strong concentration of cobalt in the district.

SPATIAL AND TEMPORAL DISTRIBUTION OF SELECTED MINERAL RESOURCES IN THE CHALLIS QUADRANGLE, IDAHO

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At least four major metallogenic events are represented in the Challis $1^{\circ} \times 2^{\circ}$ quadrangle in central Idaho. The earliest of these was syngenetic deposition of Co, Cu, Fe, Au, and minor Ag and Pb, in Precambrian sediments about 1.7 to 1.5 b.y. ago. Syngenetic deposition of Ag, Ba, Pb, V, Zn, and lesser amounts of Au, Cu, Mo, W, and Sn, took place in Ordovician to Permian time. The third event was introduction of Nb, Ta, Th, U, and the rare earth elements in pegmatites and primary minerals of the Idaho batholith, which was emplaced in several phases between 112 m.y. and 70 m.y. ago. The final event was the introduction of Be, U, Th, Mo, Sn, Au, Ag, Hg, Sb, and F during Tertiary igneous activity approximately 47 m.y. to 29 m.y. ago. Black-sand and gold placer deposits accumulated during Pleistocene and Recent time.

Previously deposited metals were remobilized during igneous and tectonic activity in the Precambrian, Cretaceous, and Tertiary. Ore minerals occur in a wide range of veins, replacements, disseminations, stockworks, and skarns associated both with the Idaho batholith and its satellite plutons and with many types of Tertiary intrusives. Most metals in these deposits are believed to have been derived from crustal sources, most likely the metalliferous Precambrian and Paleozoic sediments.

Paleozoic sediments in the south-central part of the quadrangle contain large reserves and conditional, hypothetical, and speculative resources of Pb, Zn, Mo, Ag, fluorspar, W, Ba, V, and Sn. Precambrian sediments and metamorphic rocks in the northern parts of the quadrangle contain conditional, hypothetical, and speculative resources of Co, Cu, and Au. Tertiary rocks in the Challis volcanic field and elsewhere in the quadrangle contain conditional, hypothetical, and speculative resources of Au, Ag, U, Mo, fluorspar, Sb, and zeolites. Rocks within and adjacent to the ring structures of the Thunder Mountain caldera complex contain reserves and conditional resources of Au, Ag, and W, along with hypothetical and speculative resources of the same elements and Sb, Hg, Mo, and rare earth elements. And, finally, skarns and roof pendants within and adjacent to the eastern side of the Idaho batholith contain conditional resources of W and hypothetical and speculative resources of W, Ag, Mo, Cu, Pb, and Au.

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