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U.S. GEOLOGICAL SURVEY CIRCULAR 916

Summary Mineral Resource Appraisal of the Richfield 1°×2° Quadrangle, West-Central Utah

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Department of the Interior
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SUMMARY MINERAL RESOURCE APPRAISAL OF THE RICHFIELD 1° × 2° QUADRANGLE, WEST-CENTRAL UTAH

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ABSTRACT

The mineral resource potential of the Richfield 1°×2° quadrangle, Utah, has been appraised using geological, geophysical, geochemical, and remote-sensing techniques. These studies have led to many publications giving basic data and interpretations; of these, a series of 18 maps at 1:250,000 and 1:500,000 scales summarizing aspects of the geology, geophysics, geochemistry, and remote sensing is designated the CUSMAP (Conterminous United States Mineral Appraisal Program) folio. This circular uses the data shown on these maps to appraise the mineral resource potential of the quadrangle.

The oldest rocks exposed in the Richfield quadrangle are small patches of Early Proterozoic (1.7 billion years old) gneiss and schist on the west side of the Mineral Mountains. These rocks presumably formed the basement on which many thousands of meters of Late Proterozoic, Paleozoic, and lower Mesozoic sedimentary strata were deposited. These rocks were deformed during the Late Cretaceous Sevier orogeny when Precambrian and Paleozoic strata in the western part of the quadrangle were thrust relatively eastward across Paleozoic and Mesozoic strata in the eastern part of the quadrangle. Late Cretaceous and early Tertiary highlands above the overthrust belt were eroded and much of the debris was deposited in broad basins east of the belt. Volcanism in Oligocene and earliest Miocene time formed an east-northeast-trending belt of calcalkalic volcanoes across the southern half of the quadrangle. In early Miocene time, the composition of the volcanic rocks changed to a bimodal assemblage of mafic rocks and high-silica alkali rhyolite that has been erupted episodically ever since.

Syngenetic mineral resources developed during formation of both sedimentary and volcanic rocks. These include limestone and dolomite, silica-rich sandstone, metalliferous black shale, evaporite deposits, zeolite deposits, pumice, cinders and scoria, and evaporitic or diagenetic deposits in playa environments. Most of these deposits need to have markets established, or extraction and fabrication techniques developed, for them to be utilized.

Most epigenetic deposits are of volcanogenic-hydrothermal origin. Deposits associated with calc-alkalic igneous activity largely contain Cu, Pb, Zn, Au, and Ag, and occur in a variety of types zoned around core intrusions. Younger deposits are mostly associated with silicic igneous centers belonging to the bimodal mafic-silicic igneous association. Resources associated with this latter group are likely to contain one or more of the elements Mo, W, U, Sn, Be, and F, as well as Pb, Zn, Au, and Ag. Alunite and kaolinite deposits are found at many mineralized centers. Most epigenetically mineralized areas expose only the upper, near-surface parts of the different hydrothermal systems; most of whatever mineral deposits formed in these systems probably still exist at depth, awaiting discovery. Our conclusion is that many mineralized areas have excellent possibilities for the occurrence of mineral resources.

Each of the many identified centers of mineralization is discussed briefly in this report and an estimate made of its resource potential.

INTRODUCTION

The Richfield 1°×2° quadrangle in west-central Utah (figs. 1 and 2) has been studied as part of the U.S. Geological Survey CUSMAP (Conterminous United States Mineral Appraisal Program) program in which multidisciplinary studies are used to evaluate the mineral resource potential of selected quadrangles throughout the nation. This CUSMAP appraisal of the Richfield quadrangle is limited to metallic and nonmetallic resources; coal, oil and gas, and geothermal energy resources are not considered. The Richfield quadrangle was chosen for study because preliminary data indicated that parts of the area have high mineral resource potential, and because modern geologic studies, focusing in part on mineral resources, had already been begun in several places. By expanding and integrating these local studies, and by

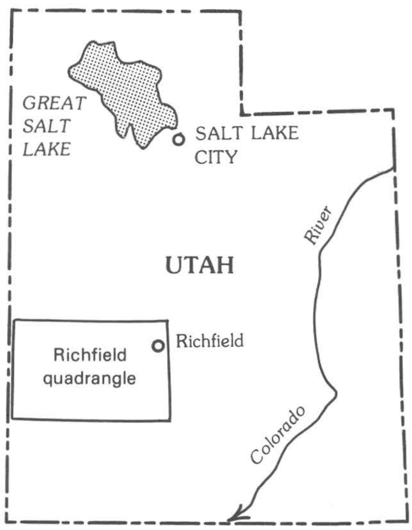

FIGURE 1.—Index map of Utah showing location of Richfield 1°×2° quadrangle.

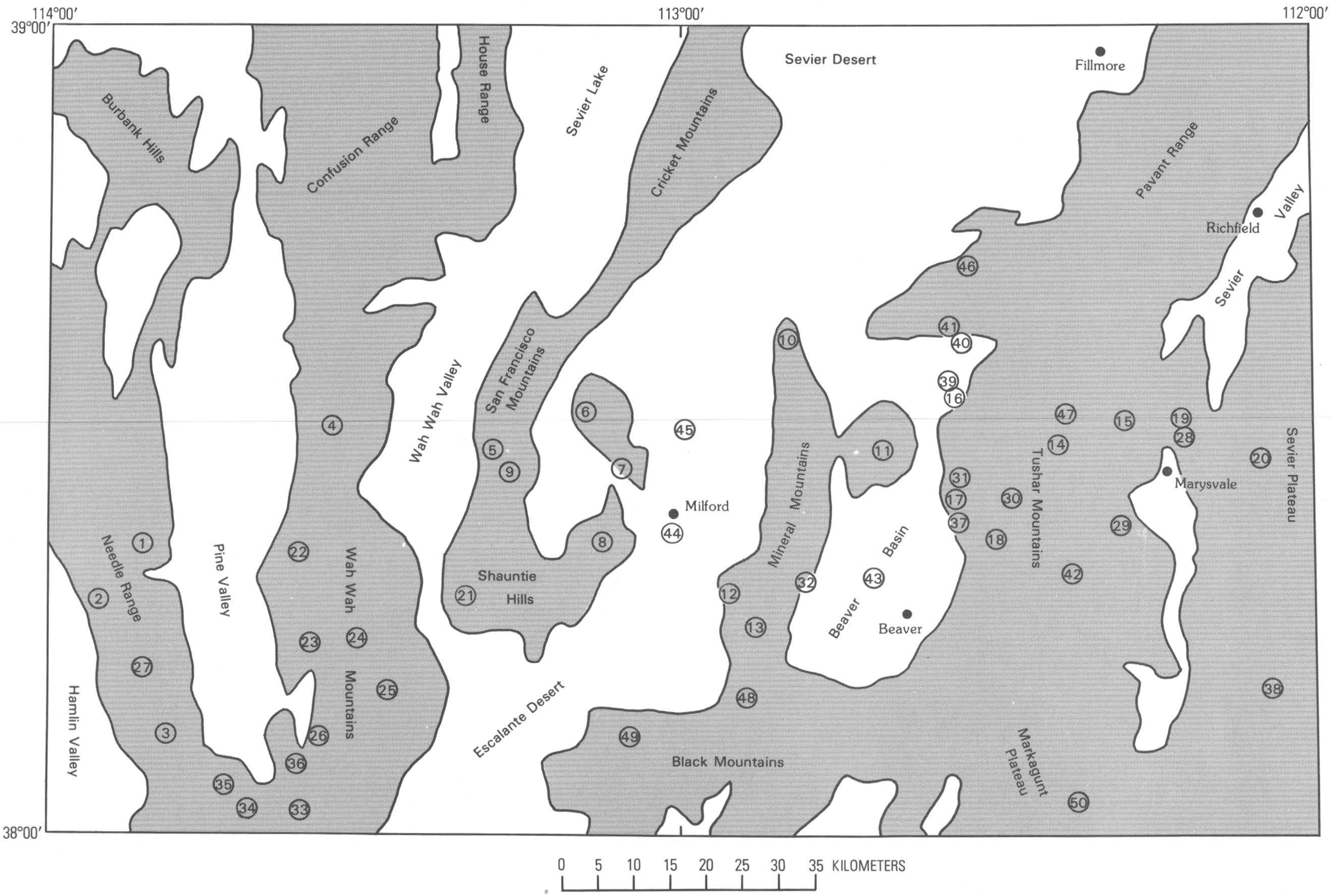

FIGURE 2.—Map showing major geographic features of the Richfield 1°×2° quadrangle, Utah. Numbered circles indicate localities discussed in text and shown on figures 3 and 4.

bringing to bear other earth science disciplines, it has been possible to identify many areas favorable for the occurrence of mineral resources. In addition, basic geological, geophysical, and geochemical parameters of important segments of the intersecting Cordilleran overthrust belt and younger Pioche-Marysvale igneous and mineral belt have been determined.

Many of the preliminary results of this study or of directly contributory precursor studies, as well as much of the basic data, have been published or released in open file as the studies progressed. This report is a brief summary designed to present the general conclusions reached by the CUSMAP studies with respect to the mineral resource potential of the Richfield quadrangle. To maintain brevity and present these conclusions without undue interruption in the narrative account, many of the supporting data and source references have been deliberately omitted. Those interested in such data and sources should consult appropriate individual references listed in the section entitled "CUSMAP products" or the more comprehensive and well-documented summary by Steven and Morris (1984, U.S. Geological Survey Open-File Report 84-521).

The general level of erosion in the Richfield quadrangle is sufficiently shallow that only the near-surface manifestations of many mineralized areas are exposed. Whatever mineral resources originally were deposited within these areas still largely exist. These near-surface indications are generally confined to a closely constrained mineral belt that extends across the full length of the quadrangle (figs. 3 and 4).

The intent of the CUSMAP program is to present a series of maps at 1:250,000 and 1:500,000 scales showing geologic, geochemical, geophysical, and remote-sensing data on the quadrangles studied, and to use these data to appraise the mineral resource potential of the quadrangles. For the Richfield quadrangle, these maps give only a part of the data base we have used in appraising the potential; numerous derivative studies have produced byproduct reports that have bearing on the resource potential. The CUSMAP folio maps are identified separately in the listing of publications from the Richfield quadrangle studies given in the section entitled CUSMAP products.

CUSMAP PARTICIPANTS

The CUSMAP studies of the Richfield quadrangle have involved many participants working on widely diverse aspects of the geology, geochemistry, and geophysics of the area. The major participants and their main fields of study are listed as follows:

GEOLOGY

T. A. Steven (U.S. Geological Survey, Denver, Colorado) (Coordinator of CUSMAP studies), Geology of igneous rocks and economic geology in eastern half of quadrangle. Co-compiler of geologic map.

H. T. Morris (U.S. Geological Survey, Menlo Park, California), Geology of sedimentary rocks, and economic geology of the western half of quadrangle. Co-compiler of geologic map.

C. G. Cunningham (U.S. Geological Survey, Reston, Virginia), Geology and economic geology of the Tushar Mountains and adjacent areas.

P. D. Rowley, (U.S. Geological Survey, Denver, Colorado) Geology of the Sevier Plateau, Black Mountains, and adjacent areas.

J. J. Anderson (Kent State Univ., Kent, Ohio, and U.S. Geological Survey), Geology of the southern Tushar Mountains and Markagunt Plateau.

M. N. Machette, (U.S. Geological Survey, Denver, Colorado), Geology of the Beaver basin.

D. L. Nielson and B. S. Sibbett, (Univ. Utah Research Inst., Salt Lake City, Utah; not formally part of CUSMAP program), Geology of the Mineral Mountains and adjacent areas.

L. F. Hintze (Brigham Young Univ., Provo, Utah, and U.S. Geological Survey), Geology of sedimentary rocks in northwestern part of quadrangle.

M. G. Best, (Brigham Young Univ., Provo, Utah, and U.S. Geological Survey), Geology of igneous rocks in southwestern quarter of quadrangle.

GEOCHEMISTRY

W. R. Miller (U.S. Geological Survey, Denver, Colorado) (general supervisor), Diverse geochemical studies.

J. B. McHugh (U.S. Geological Survey, Denver, Colorado), Water geochemistry, analytical chemistry.

J. M. Motooka (U.S. Geological Survey, Denver, Colorado), Spectrographic analytical chemistry.

GEOPHYSICS

D. R. Mabey (Utah Geological and Mineral Survey, Salt Lake City, Utah, and U.S. Geological Survey), Gravity and aeromagnetic studies.

K. L. Cook (Univ. Utah, Salt Lake City, Utah), In charge of compiling gravity map.

REMOTE SENSING

M. H. Podwysocki (U.S. Geological Survey, Reston, Virginia), Remote sensing studies.

D. B. Segal (U.S. Geological Survey, Reston, Virginia), Remote sensing studies.

WATER RESOURCE STUDIES

Don Price (U.S. Geological Survey, Salt Lake City, Utah), Water quality studies.

Numerous other contributors appear as authors or coauthors on many of the CUSMAP products listed later in this report. Their help is gratefully acknowledged.

CUSMAP PRODUCTS

A concerted effort has been made to provide the public promptly with as many as possible of the data and interpretations resulting from the CUSMAP investigations. Products from precursor studies as well as from concurrent studies not done directly for the CUSMAP program are included with the list of CUSMAP products for convenience to the reader. In the list that follows, contributory products not derived from the CUSMAP studies are indicated by the prefix (C); those products constituting the CUSMAP folio are marked by the prefix (F); and those nonfolio products derived wholly or in part from CUSMAP studies have no prefix. The products are listed alphabetically by author for each successive year; "in press" references had been approved for publication by the Director, U.S. Geological Survey by mid-1985.

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GEOLOGY AND ORE DEPOSITS

The highly varied geology of the Richfield quadrangle (fig. 3) developed over a long span of time. The oldest rocks comprise small patches of Early Proterozoic gneiss and schist that crop out along the west side of the Mineral Mountains. Sedimentation during the latest Precambrian, Paleozoic, and Mesozoic deposited a thick sequence of sedimentary rocks now exposed in the northern part of the quadrangle. This sequence was broadly deformed during the Sevier orogeny in Late Cretaceous time when allochthonous Precambrian and Paleozoic rocks were thrust eastward across Mesozoic and Paleozoic strata in the autochthon along the sinuous Sevier orogenic belt that trends diagonally southwest across the quadrangle. In early Tertiary time, erosion of highlands west of the orogenic belt, including the western part of the Richfield quadrangle, produced a wide variety of debris that accumulated in basins east of the highland. Volcanism in Oligocene and early Miocene time formed an east-northeast-trending belt of calc-alkalic volcanoes across the southern half of the quadrangle; these rocks range in composition from mafic andesite to low-silica rhyolite. In early Miocene, about coincident with the inception of extensional tectonism throughout much of the Western U.S., the composition of volcanic rocks changed to a bimodal assemblage of mafic rocks and high-silica alkali rhyolite that erupted episodically throughout the remainder of Cenozoic time. Extensional tectonism culminated in late Miocene-Pliocene time when the present basin-range topography formed through block faulting. The resulting mountain areas eroded rapidly to supply debris which was deposited in the lower parts of nearby basins.

Known and inferred mineral resources in the Richfield quadrangle are both syngenetic and epigenetic. Syngenetic resources include limestone and dolomite, silica-rich sandstone and quartzite, metalliferous black shale, evaporite deposits, zeolite deposits, pumice, cinders and scoria, and materials deposited in playa environments. The carbonate and silica resources are virtually inexhaustible but are generally unfavorably located with respect to markets. The other syngenetic resources are suspected but have not yet been discovered, or they need to have extraction or fabrication technologies developed to utilize them.

Epigenetic resources are largely of volcanogenic-hydrothermal origin. Mineralization took place many times and in many different places, and deposits can be grouped by geologic association. The earliest mineralization was related to calc-alkalic igneous centers of Oligocene age, which formed an east-northeast-trending belt across the full length of the quadrangle. Associated resources are predominantly base- and precious-metal deposits (Cu, Pb, Zn, Au, and Ag) that occur in a variety of deposit types zoned around core intrusions. During Miocene and younger times, many local rhyolite fields developed along the axis of the older belt of calc-alkalic centers. Resources or possible resources of lithophile elements (Mo, W, U, Be, Sn, and F) as well as base and precious metals (Pb, Zn, Au, and Ag) occur in association with many of the rhyolite centers. Alunite and kaolinite deposits formed by intense hydrothermal alteration at many mineralized centers.

Except for a few mineralized areas associated with calc-alkalic centers near the middle of the quadrangle, where erosion has exposed the core intrusions, most such areas expose only the upper, near-surface parts of the hydrothermal systems. This means that most of whatever mineral deposits formed in these areas still exist and await discovery. Our conclusion is that many of the mineralized areas have excellent possibilities for the occurrence of mineral resources, and that the Richfield quadrangle may be a storehouse of resources awaiting development.

MINERAL RESOURCES

Known and inferred mineral resources in the Richfield quadrangle vary from syngenetic (including diagenetic) to epigenetic (largely volcanogenic hydrothermal). Within this framework, many geologic environments favorable for the occurrence of mineral resources have been recognized. The nature of our knowledge almost nowhere permits us to assess the quantity or quality of specific mineral commodities contained in these environments. Thus, this appraisal (fig. 4) will deal largely with mineral resource potential, which has been defined as the likelihood of occurrence of mineral deposits (Taylor and Steven, 1983). A "high potential" indicates that characteristics favorable for the occurrence of mineral deposits are known to be present, or where geologic models favorable for ore accumulation are strongly supported, and evidence indicates that mineralization has taken place. "Moderate potential" indicates that characteristics favorable for the occurrence of mineral deposits are known or can be reasonably interpreted to be present, but evidence is less clear cut. "Low potential" indicates that characteristics are unfavorable for the occurrence of mineral deposits or available data do not support geologic models favorable for resource occurrence (Taylor and Steven, 1983). "Unknown potential" is assigned an area where lack of information prevents assessment. The size or grade of the resource being considered does not enter into this classification, but will be treated in the discussion that follows.

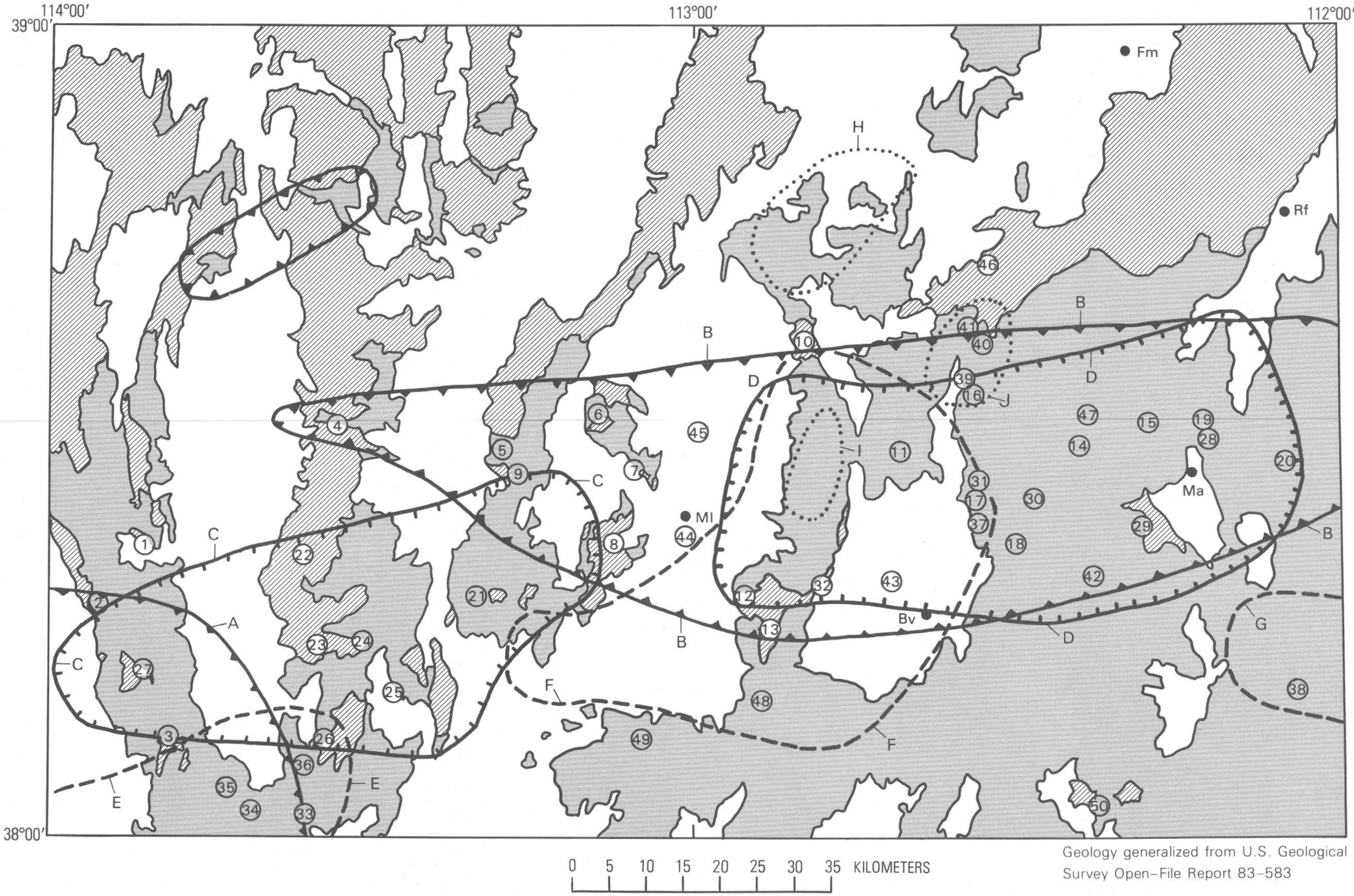
SYNGENETIC AND DIAGENETIC MINERAL RESOURCES

Syngenetic mineral resources formed as integral parts of the host rocks with which they are associated. Diagenetic resources resulted from processes that modified original constitutents of these host rocks shortly after deposition, but without significant addition of materials from external sources. The distribution of syngenetic and diagenetic resources is not shown on any illustration accompanying this report. In the discussion that follows, using the 1:250,000-scale geologic map of the Richfield quadrangle in the CUSMAP folio (U.S. Geological Survey Open-File Report 83-583, by T. A. Steven and H. T. Morris, 1983) as reference will be especially helpful.

Many of the carbonate units within the thick and extensive Paleozoic sedimentary sequence exposed in the Richfield quadrangle are chemically similar to rock quarried elsewhere in Utah for highly varied uses in industry and agriculture. Virtually inexhaustible resources of limestone and dolomite are known in the quadrangle, and the chief constraints on their development are economic factors such as transportation costs and competition with more advantageously located pits and quarries.

Silica-rich quartzite and sandstone are so abundant in the Richfield quadrangle that they constitute a virtually inexhaustible source of silica. The deposits in the Richfield quadrangle are disadvantageously located with respect to most possible markets, however, and only those exposures located close to transportation facilities can be considered even remotely economic at the present time. [Resource potential—High]

The Chainman Shale of Mississippian age crops out in narrow sinuous belts in the northwestern part of the Richfield quadrangle. The Chainman consists mainly of organic-rich shale that in general is only moderately enriched in metallic constituents compared to typical noncarbonaceous shale. Locally high concentrations of Ag, with lesser anomalously high concentrations of As, Zn, and Cu were detected in stream-sediment samples, however. In most places reexamined in the field,



Geology generalized from U.S. Geological Survey Open-File Report 83-583

EXPLANATION

Cenozoic basin-fill deposits

Cenozoic igneous rocks

Lower Tertiary to Late Proterozoic sedimentary rocks

Geologic contacts

Outline of areas containing abundant Oligocene and lowermost Miocene calc-alkalic igneous centers

- A Area containing Indian Peak caldera
- B Belt containing abundant intrusions and calderas
- Unlabelled area in northwest part of quadrangle has no known associated mineral deposits

Outline of areas of lower Miocene rhyolite volcanic rocks and intrusions

- C Area of Blawn Formation
- D Area of Mount Belknap Volcanics

Outline of areas of middle and upper Miocene rhyolite volcanic rocks and intrusions

- E Area of Steamboat Mountain Formation
- F Area of rhyolite of Gillies Hill and related rocks
- G Area of rhyolite of Phonolite Hill and related rocks

Outline of areas of Pliocene and Pleistocene rhyolite volcanic rocks or of modern solfataras

- H Area of rhyolite of Coyote Hills and Twin Peaks
- I Area of rhyolite of central Mineral Mountains
- J Area of modern solfataras near Sulphurdale and Cove Fort

(50) Identified locations discussed in text

Main settlements: Fm, Fillmore; Rf, Richfield; Ma, Marysvale; Bv, Beaver; and Mi, Milford

FIGURE 3 (above and facing page).—Map showing generalized geology and different geologic associations related to volcanogenic-hydrothermal mineralization in the Richfield 1°×2° quadrangle, Utah.

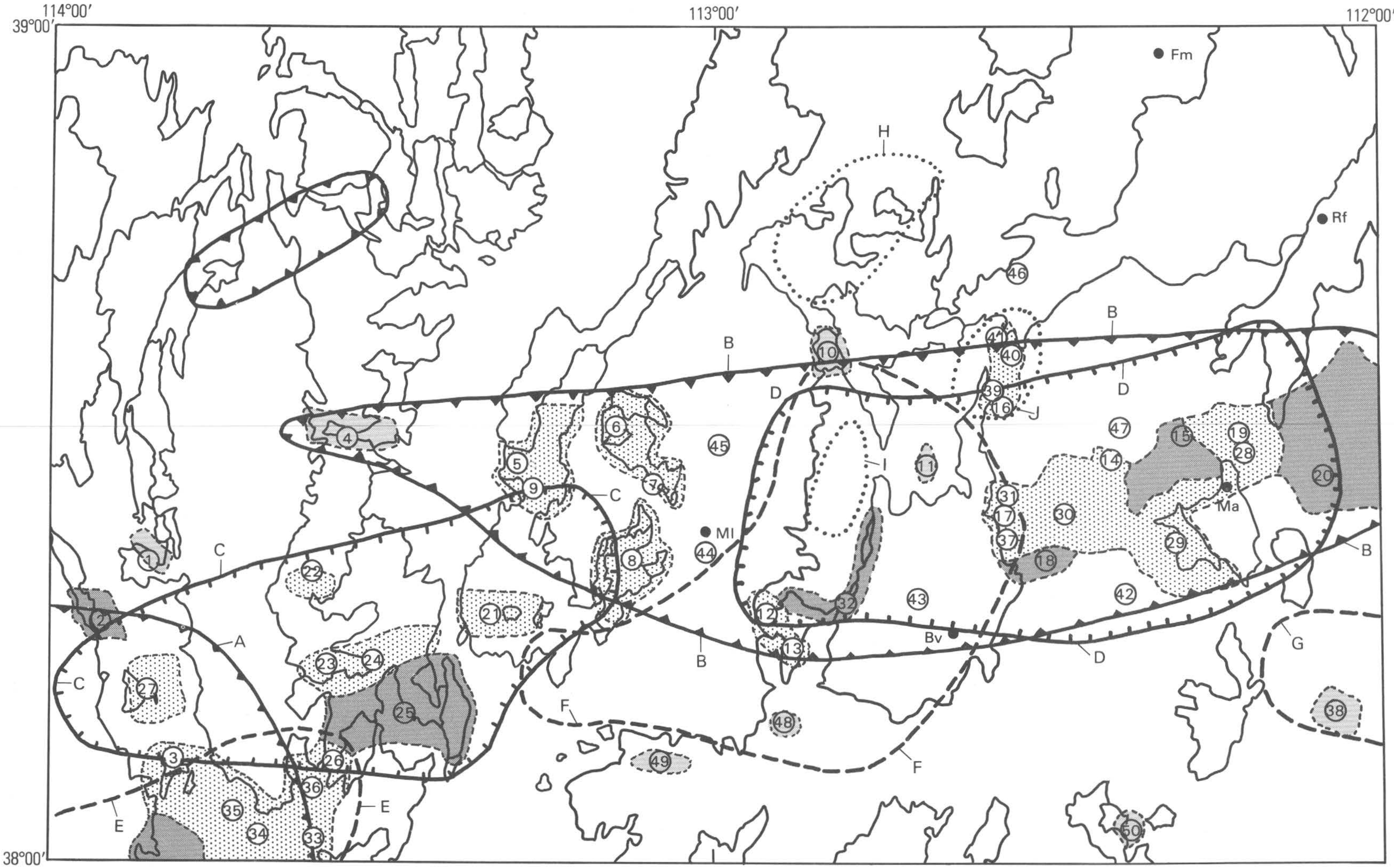
these anomalous concentrations are located near the base of the formation. The resource potential of possible favorable restricted stratigraphic zones within the Chainman cannot be assessed until much more work has been done to identify these zones and to determine their thicknesses, distributions, and metal contents. [Resource potential—unknown]

Bedded evaporite deposits of pre-Tertiary age occur in both the central and extreme northeastern parts of the Richfield quadrangle. In the Star Range, 10–12 km west of Milford, small gypsum deposits of Permian age have been explored. Despite extensive prospecting, no commercially viable gypsum-producing mines have been developed. [Resource potential—Low]

In the extreme northeastern part of the Richfield quadrangle and in adjacent areas outside the quadrangle, extensive exposures of the Middle Jurassic Arapien Shale contain thick beds of high-grade gypsum and separate deposits of halite. Near Sigurd, about 13 km northeast of Richfield, gypsum is mined and utilized in the manufacture of wallboard and other products. Elsewhere, halite has been mined and used as stock salt by local ranchers. The Arapien evaporite deposits are disadvantageously located with respect to major population centers compared to other deposits being mined in many parts of the U.S. [Resource potential—High]

Clinoptilolite (a zeolite mineral) was identified in a number of scattered localities in the Richfield quadrangle in the course of CUSMAP investigations. Most of these occurrences are in diagenetically altered nonwelded ash-flow tuff units. A total of several billion tonnes of clinoptilolite exists at three different locations in the Tushar Mountains, and much of this is readily available for open-pit mining. Other occurrences of clinoptilolite were noted in the southern Wah Wah Mountains and southern Needle (Indian Peak) Range, but no estimates of resource potential were made. [Resource potential—High]

Pumice has been mined from a frothy rhyolite lava flow of Pliocene age at the Cudahy mine in the Coyote Hills, 43 km north-northeast of Milford, and



0 5 10 15 20 25 30 35 KILOMETERS

Geology generalized from U.S. Geological Survey Open-File Report 83-583

EXPLANATION

Area having high mineral resource potential

Area having moderate mineral resource potential

Known mineralized area having low mineral resource potential

Bedrock areas having low mineral resource potential; areas underlain by basin-fill deposits have unknown mineral resource potential

Geologic contacts. See figure 3 for generalized geology

Outline of areas containing abundant Oligocene and lowermost Miocene calc-alkalic igneous centers

- A Area containing Indian Peak caldera
- B Belt containing abundant intrusions and calderas
- Unlabelled area in northwest part of quadrangle has no known associated mineral deposits

Outline of areas of lower Miocene rhyolite volcanic rocks and intrusions

- C Area of Blawn Formation
- D Area of Mount Belknap Volcanics

Outline of areas of middle and upper Miocene rhyolite volcanic rocks and intrusions

- E Area of Steamboat Mountain Formation
- F Area of rhyolite of Gillies Hill and related rocks
- G Area of rhyolite of Phonolite Hill and related rocks

Outline of areas of Pliocene and Pleistocene rhyolite volcanic rocks or of modern solfataras

- H Area of rhyolite of Coyote Hills and Twin Peaks
- I Area of rhyolite of central Mineral Mountains
- J Area of modern solfataras near Sulphurdale and Cove Fort

(26) Identified locations discussed in text

Main settlements: Fm, Fillmore; Rf, Richfield; Ma, Marysvale; Bv, Beaver; and Mi, Milford

FIGURE 4 (above and facing page).—Map showing mineral resource potential for volcanogenic-hydrothermal mineral deposits in the Richfield 1°×2° quadrangle, Utah.

considerable pumice still remains in the unmined part of the flow. None of the other rhyolite lava flows exposed in this vicinity is nearly as vesiculated as the one developed by the Cudahy mine, and it is virtually impossible to predict if hidden pumiceous flows exist without physical exploration. [Resource potential—Unknown]

Playa lakes, represented in the Richfield quadrangle by the Pine Valley Hardpan, Wah Wah Valley Hardpan, and Sevier Lake, are ephemeral sumps that have trapped stream drainage in western Utah since middle Tertiary time. Former playas probably exist in many places and at different depths within the sedimentary fill in structural basins in the western part of the Richfield quadrangle. Such former playa lakes might act as ultimate repositories of soluble elements not sorbed onto clay or zeolite minerals, or otherwise dispersed through the basin-fill sediments.

Very few data are available on which to judge the economic potential of playa deposits in the Richfield quadrangle. Some shallow drilling in the Sevier Lake area has been interpreted to indicate that a significant resource of lithium exists there, but the possibility that evaporative pumping has increased near-surface concentrations appreciably and, thus, biased the data does not seem to have been adequately considered. Uranium contents at Sevier Lake are comparable with or lower than contents of other playa lake sediments that have been tested in the Great Basin. The relatively low contents of Li and U in the Sevier Lake sediments and brines seem surprising inasmuch as the two main drainage systems tributary to Sevier Lake, the Sevier and Beaver Rivers (not shown on fig. 2), drain extensive volcanic areas with known Li and U source rocks. However, relatively high Li and U contents in Sevier River water where it passes through the Marysvale volcanic field are greatly diluted downstream toward the Sevier Lake playa. The long transit distance also allows for sorption onto clays or zeolites as well as dilution by barren water and sediment, which leads to dispersal.

The many seeming contradictions in published data and interpretations dealing with the Sevier Lake and other playas in the Richfield quadrangle can be resolved only by using a vastly larger data base than is now available. Obtaining this would require extensive physical exploration, which is beyond the scope of the present investigation. [Resource potential—Unknown]

Glacial Lake Bonneville occupied the lower parts of basins in the north-central part of the Richfield quadrangle. Sand and gravel occur in bars, spits, and deltas around the margin of the former lake, and fine-grained impure marl covers much of the former lake bottom. Sand dunes of gypsum crystals occur locally, particularly a few kilometers southwest of the town of Fillmore, and some of this material has been mined and sold for agricultural purposes. No large resource of the material exists, but the gypsum dunes are easily mined and are convenient to transportation facilities. The conventional sand and gravel deposits are extensively used locally. [Resource potential—High]

Pliocene and Pleistocene cinder cones, which occur widely in the north-central part of the Richfield quadrangle, have been intermittent sources of cinders and scoria. Large resources still remain. [Resource potential—High]

EPIGENETIC MINERAL RESOURCES

Epigenetic deposits formed by introduction of material into a host rock by one or more processes not related to the development of that host. Most known or anticipated epigenetic deposits in the Richfield quadrangle formed by volcanogenic hydrothermal processes, although mineral concentrations deposited in basin-fill sedimentary rocks from water draining adjacent volcanic areas also may exist.

Epigenetic mineralization in the Richfield quadrangle took place many times and in many different places, and in the aggregate it formed a well-defined mineral belt that extends east-northeast across the full length of the quadrangle (figs. 3 and 4). These episodes can be separated according to geologic association, beginning with mineralization related to calc-alkalic igneous centers in Oligocene time, and progressing through successive periods of Miocene and younger silicic rhyolite intrusion, extrusion, and related mineralization. Hydrothermal activity is still in progress in the Cove Fort-Sulphurdale area at the northwest border of the Tushar Mountains.

MINERALIZED AREAS ASSOCIATED WITH OLIGOCENE AND EARLY MIOCENE CALC-ALKALIC ROCKS

Oligocene to early Miocene dioritic to quartz monzonitic intrusions cut sedimentary units and calc-alkalic volcanic rocks in many places in the Richfield quadrangle, and evidence for associated hydrothermal activity is widespread. Most of the known mineral deposits associated with these areas of intrusions contain Cu, Pb, Zn, Au, and Ag.

A number of scattered areas showing evidence of hydrothermal activity related to eruption of the middle Oligocene Needles Range Group have been recognized in the southern Needle (Indian Peak) Range (Area A, figs. 3 and 4). Two of these mineralized areas are associated with quartz monzonitic intrusions emplaced during resurgent stages of the Indian Peak caldera cycle, and one formed later during subsequent Needles Range magmatism. Mineralized areas most clearly associated with calc-alkalic intrusions are the Sawtooth Peak area (locality 1) and Miners Cabin Wash area (locality 2) along or near the northern margin of the Indian Peak caldera, and in the Arrowhead mine-Bob Leroy Peaks area (locality 3) within the resurgently domed core of the caldera.

Near Sawtooth Peak, highly faulted Ordovician carbonate rocks and overlying Tertiary volcanic rocks contain small masses of iron-oxide-stained limestone and ferruginous jasperoid along some of the fractures. No base- or precious-metal ore minerals have been recognized. [Resource potential—Low]

In the Miners Cabin Wash area on the west side of the southern Needle (Indian Peak) Range, small bodies of granodiorite and quartz monzonite cut faulted lower Paleozoic carbonate strata and overlying Oligocene volcanic rocks. Mineralized rock occurs in skarn and marble along intrusive contacts, or in minor replacement bodies and veins in breccia zones along faults that cut nearby carbonate strata. Small reefs of jasperoid have recently (1983) been the focus of industry exploration for precious metals. Total production from the Miners Cabin Wash area was probably no more than a few thousand tonnes of lead-silver ore. [Resource potential—Low]

At the Arrowhead (Calumet) mine and nearby mines in the southern Needle (Indian Peak) Range, known mineral deposits are largely confined to Paleozoic sedimentary strata, but peripheral volcanic rocks to the south are in part silicified, argillized, and pyritized. The Arrowhead area has produced about 5,000 tonnes of base- and precious-metal ore. The Arrowhead area is within the resurgent core of the Indian Peak caldera, but mineralization was probably younger than the caldera cycle. The altered zones are in part localized by faults, and in part form thick masses of dark jasperoid replacing Paleozoic carbonate rocks as well as regolith along the contact between sedimentary and volcanic rocks. The ore deposits that have been mined consist of small and sparsely distributed tabular and pod-shaped masses of partly oxidized silver-lead-zinc ore in a gangue of jasperoid, dolomite, and barite. The large masses of jasperoid are reported to contain precious-metal values and are currently (1983) being explored by industry. [Resource potential—Moderate to High]

Another concentration of calc-alkalic intrusive bodies forms a well-defined belt across the middle of the eastern three-fourths of the Richfield quadrangle (Area B, figs. 3 and 4). The Wah Wah Pass area (locality 4) in the central Wah Wah Mountains is the site of a cluster of igneous intrusions (largely diorite and lesser rhyolite) cutting an east-dipping homocline of Paleozoic sedimentary rocks. The dioritic plutons probably mark the sources of volcanic rocks exposed nearby. Adjacent sedimentary rocks were converted locally to marble and skarn, and the volcanic units were weakly pyritized and argillized. Small gossanlike bodies of iron oxides in Cambrian carbonate rocks appear to contain only hematite, limonite, and manganese oxides. No production has been recorded, and no significant amounts of ore minerals were recognized on mine dumps. [Resource potential—Low]

A tract nearly 30 km across, west and northwest of Milford, contains many mineralized areas associated with calc-alkalic igneous intrusions. These mineralized areas have supplied the great majority of mineral products produced so far in the Richfield quadrangle. Erosion here has cut to the lower volcanic or upper subvolcanic levels, exposing the hypabyssal intrusions and their associated mineral deposits. Equivalent levels in most other mineralized areas in the Richfield quadrangle are still largely buried and the associated mineral deposits hidden. Mineralized rock in core plutons has been mined mainly at the Cactus mine (locality 5) in the southern San Francisco Mountains and the OK mine (locality 6) in the Beaver Lake district. Skarns commonly formed in carbonate strata adjacent to plutons in the San Francisco Mountains, Beaver Lake Mountains, and Rocky Range. Many of these skarn bodies contain ore minerals, but most of the skarn ore that has been mined has been from the Rocky district (locality 7). Vein and replacement ore bodies containing largely lead, zinc, silver, gold, and minor copper also are widely distributed in sedimentary and volcanic rocks peripheral to the intrusive bodies, especially in the San Francisco Mountains and Star Range (locality 8). The Horn Silver mine in the San Francisco district (locality 9), which is developed on the largest known replacement ore body in the area, and has produced about 735,000 tonnes of silver-lead-zinc-copper-gold ore.

The mineral resource potential of the area west and northwest of Milford depends on the environment. The core intrusions exposed in all the mineralized areas seem to have a low potential. The potential for undiscovered skarn-type, and vein- and replacement-type mineral deposits is considered high, especially for small- to moderate-sized deposits similar to those already mined. The major Horn Silver deposit may be unique in its large size and geologic occurence. All the known mineralized districts are bounded in part by younger sediment-filled basins, and buried ore deposits could exist in peripheral parts of these districts, as well as in totally hidden mineralized centers. [Resource potential—High)

The Mineral Mountains consist primarily of intrusive rocks that form a composite batholith consisting of numerous individual intrusive bodies emplaced during three different episodes of igneous activity. The oldest activity took place in latest Oligocene and earliest Miocene time when numerous small dioritic to quartz monzonitic intrusions were emplaced. Mineralized rock related to these early intrusive rocks has been recognized in the Antelope district at the north end of the mountains (locality 10), in the Fortuna mine area (locality 11) along the east margin of the batholith, and in the Bradshaw (locality 12) and Lincoln (locality 13) districts at the south end of the mountains. The Antelope district has been prospected sporadically from 1871 until recent times, but little ore has been shipped. The ore bodies consist of small pods and stringers of relatively soft and incoherent lead ore that occur adjacent to bedding planes and steep faults cutting Cambrian limestones. The strongly oxidized ore consists of nodules of galena, cerussite, and anglesite embedded in porous ochre. Barite is abundant locally. The small record of production and general absence of extensive zones of hydrothermally altered rock suggest low potential for the occurrence of significant mineral deposits in the Antelope district. [Resource potential—Low]

The Fortuna mine area is in the low hills between the Mineral and Tushar Mountains at the north end of Beaver basin, where a 1- to 2-km-wide belt of propylitically altered lava flows is exposed for nearly 8 km along the eastern margin of the Mineral Mountains batholith. The volcanic rocks are intensely altered and are cut by east-trending fissures marked by pyrite-bearing quartz veins and argillically altered rock. Spotty native gold has been reported in the oxidized parts of the veins. A few small workings exist, probably in areas showing low-grade gold values, but total production probably did not exceed a few hundred tonnes of rock. In all probability, only small pockets of low-grade gold ore exist in this area. [Resource potential—Low]

The Bradshaw mining district in the southwestern part of the Mineral Mountains has produced about 10,000 tonnes of gold-silver-copper-lead-zinc ore. Most ore consists of pulverulent limonitic ochre containing grains and nodules of cerussite, anglesite, and galena as well as important amounts of gold and silver; the ore partly filled a series of caves localized along obscure east-trending fissures in limestone. The nearby Lincoln district in the southern Mineral Mountains produced an estimated 7,000 tonnes of similar ore from small tabular and podlike replacement bodies in limestone. Shallow ores from the Lincoln district consist of soft, vuggy mixtures of calcite and iron oxide with local concentrations of secondary lead, zinc, and copper minerals; at increasing depths, sulfide ores containing pyrite, sphalerite, galena, and chalcopyrite are encountered. Tungsten-bearing ore consisting of scheelite crystals scattered through irregular bodies of porous limonite has been produced from the Creole mine. The small size and nonpersistent character of the known ore bodies in the Bradshaw and Lincoln districts suggest little chance for large concealed ore bodies, although a good possibility exists for undiscovered ore bodies of the type and size already mined. [Resource potential—Moderate to High]

Latest Oligocene-earliest Miocene monzonite and quartz monzonite intrusive bodies cut the intermediate-composition volcanic rocks at many places in the central and northern Tushar Mountains. The volcanic wallrocks around some of these bodies have been extensively propylitized, and locally the rock has been further converted to argillic assemblages. Pyrite-bearing quartz-carbonate veins occur in some of the altered rocks, and in places these veins carry spotty gold and silver values that have encouraged widespread prospecting. The only area that has had significant production is the Kimberly district (locality 14) in the north-central part of the Tushar Mountains where several million dollars worth of gold and silver were produced during episodic mining between 1892 and 1937. The ores produced came chiefly from the oxidized parts of two persistent vein zones cutting propylitized quartz monzonite intrusive rock. Metal values appear to drop off significantly in unoxidized ores in the lower levels of the old mines.

Other areas in the northern and central Tushar Mountains where gold- and silver-bearing quartz-carbonate veins cut altered volcanic rocks are the Deer Flat area (locality 15) north of lower Deer Creek, the Butler-Beck mine area in the headwaters of Deer Creek and 5 km east of the Kimberly district, a small area a few kilometers southeast of Sulphurdale (locality 16), the Rob Roy mine (locality 17) near the mouth of Indian Creek Canyon, and the Cork Ridge area (locality 18) south of the Mount Belknap caldera. In all these places the quartz veins appear to form small pods or lenses along fissure zones; unverified oral reports suggest that although local pockets of rich ore occur in places, most gold and silver values are low. [Resource potential—High for the Kimberly area; Moderate to Low elsewhere]

The roots of the Monroe Peak caldera in the east-central part of the Richfield quadrangle were widely invaded by quartz monzonitic magma shortly after collapse about 23 Ma. Volcanic rocks adjacent to and overlying some of the cupolas of intrusive rock were locally intensely altered to argillic and advanced argillic mineral assemblages. Most of the replacement alunite deposits north and northeast of Marysvale, which have been the focus of intermittent exploration and development interest for many decades, were formed at this time.

An igneous cupola called the Central Intrusive exposed in the southern Antelope Range (locality 19) is virtually surrounded by a series of 23 Ma replacement alunite deposits that mark the cores of many hydrothermal convection cells. These alunite deposits are interpreted to have formed in a near-surface environment above the buried margin of a cooling pluton that reacted with evaporite-bearing strata in its walls to supply sedimentary sulfur to overlying hydrothermal cells. Near-surface reaction of this sulfur with atmospheric oxygen led to the strongly acidic alteration of volcanic rocks, with development of alunite and related products. The core pluton shows little evidence of associated porphyry-type deposits, but adjacent carbonate strata could well have been converted to skarn, and the different overlying hydrothermal cells may have deposited replacement-type and fissure vein-type deposits in a zone outside the contact-metamorphic aureole. Weak and sporadic anomalous metal values at the surface have discouraged exploration at shallow levels, but deeper-level deposits may exist.

The Marysvale Peak and Manning Creek alunite deposits (locality 20) and the Box Creek kaolinite deposit exposed farther east in the Monroe Peak caldera indicate broadly analogous environments. Surface rocks and stream sediments of this area, however, are nearly devoid of anomalous metal values. Post-caldera intrusion beneath the center of the caldera apparently has cut out the sedimentary strata in this vicinity, so little likelihood exists for deep replacement or skarn deposits. Only a low to moderate potential is deemed to exist for vein deposits. Alunite has periodically been proposed as a possible source of potash, alumina, and sulfuric acid. The Monroe Peak caldera area obviously has a high potential for alunite (and kaolinite) resources. [Resource potential—High for alunite and kaolinite; Moderate for hidden vein, replacement, or skarn-type deposits]

MINERALIZED AREAS ASSOCIATED WITH EARLY MIOCENE BLAWN FORMATION

Rhyolitic rocks in the Blawn Formation (23–18 Ma) constitute the oldest silicic rock accumulation in the bimodal mafic-silicic igneous suite that was erupted widely in the Richfield quadrangle in later Cenozoic time. Dikes and stocks, thick lava flows, and widespread ash-flow tuff sheets in this formation are exposed over a northeast-trending area at least 70 km long and as much as 35 km wide in the southwestern part of the quadrangle (Area C, figs. 3 and 4). Hydrothermal activity associated with intrusive centers took place in all major areas of exposure of the Blawn Formation, and deposits containing lithophile elements such as Mo, W, U, Sn, and Be, and F, as well as Pb, Zn, Au, and Ag may exist in places.

In the Shauntie Hills (locality 21) in the central part of the Richfield quadrangle, Oligocene and early Miocene calc-alkalic volcanic rocks surrounding a few isolated exposures of sedimentary rocks marking the tops of prevolcanic hills are overlain by small areas of silicic volcanic rocks of the Blawn Formation. A belt of extensively altered rocks, 2–4 km wide, extends about 12 km east from the western margin of the southern Shauntie Hills, across and several kilometers beyond a prominent hill of sedimentary rocks called White Mountain (just east of locality 21). Alteration took place about 22.5 Ma and converted large masses of rock to alunite and kaolinite. Small deposits of uranium and native sulfur occur locally. The area west of White Mountain may contain 80 million tonnes of alunitic rock containing 14.5 percent Al_2O_3 and 3.15 percent K_2O. These areas of altered and mineralized rock are typical of those that form in near-surface solfataric environments where hypogene H_2S reacts with atmospheric oxygen to form sulfuric acid. Other types of mineral resources may have been deposited under much different conditions deeper within the hydrothermal systems. Assuming intrusive igneous roots for the hydrothermal systems, porphyry-type deposits may have formed near the tops of the postulated intrusions, and skarn, replacement, and vein types progressively outward. All bodies of silicified rock, whether jasperoid associated with carbonate strata or highly silicified volcanic rocks, are possible hosts for precious metals. Whether valuable metals were in fact deposited cannot be determined until much detailed study is done. [Resource potential—High for alunite and kaolinite; Moderate or Unknown for metallic resources]

The Pine Grove district (locality 22) in the west-central Wah Wah Mountains has produced an estimated 2,600 tonnes of gold-silver-copper-lead-zinc ore from small replacement ore bodies in carbonate strata. A large, deeply buried stockwork molybdenum-tungsten deposit was discovered by Phelps-Dodge Mining Company in 1977. The mineralized area centers on two contiguous small stocks of quartz latite or quartz monzonite that were intruded about 24 Ma. The igneous rocks are in part moderately to strongly argillized, silicified, sericitized, and pyritized. The ore bodies mined in the past were in fault-bounded blocks of limestone and shale that were partly replaced by ore and gangue minerals. The deeply buried molybdenum-tungsten ore body is a typical porphyry-type deposit associated with an altered hypabyssal intrusion. The top of the deposit is reported to lie at depths of 900 to 2,000 m below the surface. [Resource potential—High]

A number of scattered mineralized or possibly mineralized areas have been identified throughout the southern Wah Wah Mountains within an area known to have at least some igneous centers related to the Blawn Formation. Hydrothermal activity in several of these areas is known to have taken place during the Blawn igneous episode, and that at the others is postulated to have taken place at about the same time. At the Staats mine (locality 23) a 20-Ma rhyolite intrusion about 2 km long and 0.5 km wide cuts Paleozoic quartzite and dolomite. The brecciated wallrock around the plug contains lenses of uranium-bearing fluorite from which about 4,500 tonnes of metallurical fluorspar and 1,700 tonnes of uranium ore (uranium-bearing fluorspar) have been shipped. Some cassiterite also has been reported. Four large areas of alunitized and kaolinitized tuffaceous rocks occur within an area about 6 km across on and near the lower eastern slopes of Blawn Mountain (locality 24). Samples of alunite from one of the deposits have been dated as 22.5 to 20 Ma, indicating that alteration took place during the Blawn period of igneous activity. The strongly altered rocks are closely limited to a specific stratigraphic interval just above and below the unconformity between the Needles Range Group and Blawn Formation where large irregular masses of the host rocks have been pervasively replaced. Administrative estimates by the U.S. Bureau of Land Managment indicate that one of the areas contains about 150 million tonnes of alunitic rock averaging 14.45 percent Al_2O_3, and two other areas are of similar magnitude. The fourth area is about the same size but is dominantly kaolinite. A major resource for alunite clearly exists in these altered areas. If the altering hydrothermal systems had their source in hidden intrusions, as seems likely, zoned hydrothermal metal deposits may exist at the intrusive, skarn, replacement, and vein levels at depth. [Resource potential--High]

The Blue Mountains-Jockey Spring area (locality 25) is an ill-defined area about 20 km long northeastward and 15 km across in the southern Wah Wah Mountains, south and southeast of the Staats mine and the highly altered areas east of Blawn Mountain. This area is characterized by three structural domes with thrust-faulted Paleozoic and Mesozoic sedimentary rocks in their cores, surrounded by Tertiary volcanic rocks. The principal prospects in the area are the Blawn Wash, Emma, and Iron Duke mines in the western Blue Mountains, which expose small, noncommercial bodies of manganiferous limonite, geothite, and earthy hematite along fractures in Cambrian carbonate strata; the resource potential of these deposits as sources of iron ore is negligible. The Katie (Cima) mercury and sulfur mine (locality 26), 5 km south-southwest of Jockey Spring, has produced a small quantity of native sulfur and cinnabar ore which was mined from argillized and silicified tuff in the Blawn Formation; the age of this deposit is uncertain and it may be related to either the Blawn or the younger Miocene Steamboat Mountain period of igneous activity. The most promising target for undiscovered mineral resources in the Blue Mountains-Jockey Spring area seems to be at depth within the domed areas. These domes appear to have been uplifted by vertical forces, probably by magmatic pressure from hidden intrusions. The most favorable area to test this possibility appears to be about half a kilometer northwest of Blue Peak in the Blue Mountains, where Mesozoic rocks have been in part converted to hornfels, including calc-silicate minerals, probably by an underlying intrusive body. [Resource potential—Moderate]

Fluorspar deposits in the Indian Peak area (locality 27) in the southern Needle (Indian Peak) Range have produced a total of about 20,000 tonnes of ore containing 25–50 percent CaF_2. The fluorspar-producing area is entirely within the resurgent core of the 30–29 Ma Indian Peak caldera, but mineralization was significantly later than development of the caldera and seems to have been associated with fluorite-bearing rhyolite dikes of probable Blawn Formation age. The fluorspar deposits occur as local shoots along well-defined zones of fissured and brecciated rock cemented by quartz, lamellar calcite, and spotty concentrations of fluorite. The largest producing properties are the Cougar Spar and Holt-Bluebell mines. A moderate to good possibility exists that other fluorspar deposits of the type already mined occur along the known vein zones, but it seems much less likely that other vein zones not yet prospected will be found. [Resource potential—High to Moderate]

MINERALIZED AREAS ASSOCIATED WITH EARLY MIOCENE MOUNT BELKNAP VOLCANICS

The Mount Belknap Volcanics was erupted from two source areas in the northern Tushar Mountains and Antelope Range (Area D, figs. 3 and 4) between 21 and 14 Ma. Hydrothermal activity took place many times and in many different places in association with Mount Belknap igneous centers, and many environments have been identified that seemingly have good possibilities for containing important undiscovered mineral resources, mostly of lithophile elements. Igneous activity in the eastern source area took place 21–14 Ma. Mineralization about 19 Ma deposited uranium-bearing veins in the Central Mining Area (locality 28); between 1949 and 1967 these veins supplied 175,000 tonnes of uranium ore averaging 0.20 percent U_3O_8. Molybdenum is associated with the uranium and is increasingly abundant downward. The uranium-molybdenum deposits are believed to be related to a hidden intrusion that possibly may contain a porphyry-type disseminated molybdenum deposit. Low-grade uranium values reportedly were encountered in extensive exploration drilling by industry in a several-kilometer-wide belt east of the main uranium-producing Central Mining Area. [Resource potential—High]

A major composite hydrothermal system developed in the Tushar Mountains at the southwest end of the eastern source area about 14 Ma. Two adjacent and approximately coeval centers located at Alunite Ridge and at the top of Deer Trail Mountain (locality 29) are marked by intensely altered rocks: at Alunite Ridge major alunite veins as much as 20 m thick filled open fissures in a structural dome cut by radial fractures, and on Deer Trail Mountain highly kaolinitized rocks mark the focus of another radial fracture pattern. These areas are believed to overlie cupolas on a hidden stock. Precious- and base-metal deposits occur in an annular ring surrounding the intensely altered cores. Quartz veins containing gold, silver, and minor base metals cut propylitized volcanic rocks in part of this annular ring, and the Deer Trail mine exploits a manto in carbonate strata along the east side of the ring. The Deer Trail mine has produced about 250,000 tonnes of base- and precious-metal ore. The igneous cupolas postulated to underlie Alunite Ridge and Deer Trail Mountain have an excellent chance for hosting porphyry-type disseminated copper and molybdenum deposits, metal-bearing skarn deposits may border the intrusions, and more replacement deposits (comparable to the Deer Trail manto) and vein deposits (like those exposed in nearby volcanic rocks) may exist in the surrounding wallrocks [Resource potential—High]

The western source area of the Mount Belknap Volcanics was violently active about 19 Ma when the Joe Lott Tuff Member was erupted and the Mount Belknap caldera (locality 30) subsided. Several environments favorable for forming mineral deposits existed during and following caldera development. Interlayered densely welded ash-flow tuff and thick lava flows filling the caldera were locally cut by small intrusions above the southern ring fracture zone. The fill was pervasively bleached and altered shortly after it accumulated, and small areas near some of the intrusions were extensively argillized and pyritized by local hydrothermal activity. Uranium and molybdenum anomalies in stream-sediment and rock samples were detected near some of the intrusions; they have been interpreted as indicating a potential for porphyry-type mineral deposits near the tops of exposed or hidden intrusive bodies. The pervasively altered caldera fill shows evidence of remobilization of uranium and other elements. Remobilized uranium was selectively deposited in more permeable parts of the caldera fill, both in talus-mudflow breccia at the margins of intracaldera lava flows, or in tongues of talus-landslide breccia extending from the caldera walls into the fill. Beryllium also is irregularly anomalous in the caldera fill, but the precise sources of the anomalies have not been determined. Some of the bodies of rock containing redeposited elements may be large enough and of high enough grade to constitute mineral resources. [Resource potential—High]

Combined geologic, geochemical, geophysical, and geochronologic data indicate that an area along Indian Creek between the Mount Belknap caldera and Beaver basin (locality 31) may be underlain by a mineralized intrusion that was emplaced about 16 Ma. Rhyolite dikes containing fluorite and uranium occur in an area that is also marked by a strong aeromagnetic low, and remote-sensing techniques have determined that this same area has been pervaded by potassium- and uranium-bearing solutions which increased the contents of these elements significantly throughout the area of the magnetic anomaly. The pluton interpreted to underlie this area could well have zonally arranged mineral deposits associated with it. [Resource potential—High]

MIOCENE MINERAL DEPOSITS IN THE MINERAL MOUNTAINS

Most of the composite Mineral Mountains batholith (western part of Area D, figs. 3 and 4) consists of granite and quartz monzonite plutons as large as 6×10 km across that were emplaced approximately concurrently with eruption of the Mount Belknap Volcanics farther east. The contacts of some of these early Miocene intrusions with Paleozoic carbonate strata are marked by skarn zones that locally contain the tungsten mineral scheelite. Most prospects in the Mineral Mountains are located along a 5–6 km segment of the contact zone between Miocene granitic intrusive rocks and Mississippian Redwall Limestone along the southeastern flank of the mountains (locality 32). A small quantity of beryllium from beryl and helvite was produced from pegmatite dikes cutting the contact zone at one mine. The tungsten deposits occur in garnetiferous skarn zones in the carbonate strata adjacent to or near the intrusive contact. Scheelite, although sparsely disseminated to absent through most of the skarn, locally forms higher grade pockets a few tonnes to several tens of tonnes in size that contain as much as several percent WO_3. The tungsten ore bodies are small and erratically distributed, and most of the skarn is effectively barren. Total production from this area has been about 1,000 tonnes of ore containing 0.5–1 percent WO_3. [Resource potential—Moderate to Low]

MINERALIZED AREAS ASSOCIATED WITH MIDDLE MIOCENE STEAMBOAT MOUNTAIN FORMATION

An area in the southern Wah Wah Mountains and southern Needle (Indian Peak) Range about 25 km long northeast and 15 km across within the Richfield quadrangle contains large areas of 13–12 Ma rhyolite in the Steamboat Mountain Formation (Area E, figs. 3 and 4). Hydrothermally altered rocks are prominent at several places within this area, and weak to strong geochemical anomalies generally of lithophile elements have been detected in stream-sediment samples. Areas of hydrothermally altered rocks associated or possibly associated with the Steamboat Mountain Formation occur from the Katie (Cima) mine area (locality 26) southward to the vicinity of Mountain Spring Peak (locality 33), westward to the Bible Spring fault zone (locality 34), and then northwestward to Typhoid Spring (locality 35). The altered areas range from small patches a few meters in diameter to large areas as much as 7 km across. Some of the altered areas are closely localized along the northeast-trending Bible Spring fault zone, or along its trend northeastward (locality 36) where it projects directly toward the Katie (Cima) sulfur-mercury deposit, and some are more randomly scattered or are associated with local igneous centers of Steamboat Mountain age.

The Bible Springs fault zone and its projected extensions seem especially favorable for the occurrence of mineral resources. Geochemical sampling of stream sediments and bedrock within this area disclosed weak to strong anomalies in many elements that may have been derived from hidden highly differentiated felsic intrusions, some of which may contain porphyry-type molybdenum deposits. Not only does the porphyry environment seem likely to contain mineralized rock in certain favorable locations, but the surrounding wallrocks also are possible hosts to skarn, replacement, or vein-type deposits. Present exposures are near the top of the original volcanic accumulation, so potential ore deposits may be relatively deep. [Resource potential—High]

MINERALIZED AREAS ASSOCIATED WITH THE MIDDLE MIOCENE RHYOLITE OF GILLIES HILL

Silicic igneous rocks were emplaced widely over east-central Richfield quadrangle in middle Miocene time (10–7 Ma) (Area F, figs. 3 and 4). Remnants range from large volcanic domes at the north end of Beaver basin (rhyolite of Gillies Hill), to porphyritic and aphyric dikes and plugs cutting the batholithic core of the Mineral Mountains, and to scattered small volcanic centers on the west side of the Mineral Mountains and northern part of the Black Mountains. Hydrothermal activity related to this period of igneous activity has been recognized only along the fault marking the western margin of the Tushar Mountains, where samples of alunite from two localities have been dated as about 9 Ma. The Sheep Rock alunite deposit (locality 37), located about 16 km northeast of Beaver, forms the core of a zoned hydrothermal system that has the Sheep Rock and Sunday gold mines in its periphery. The alunite deposit formed by near-surface oxidation of H_2S to sulfuric acid, which converted a local mass of volcanic rock to alunite and kaolinite. The gold deposits consist of quartz-calcite veins containing shoots of manganese oxides, gold, silver-bearing minerals, and pyrite. Combined geological, geophysical, and remote-sensing data suggest that the Sheep Rock area probably is underlain by a 9-Ma intrusion which localized an overlying hydrothermal system. Potassium, uranium, and thorium pervaded the overlying rocks, and gold and other metals were deposited in veins in peripheral parts of the system. The potential for ore deposits in the buried porphyry, skarn, and replacement environments is not known, but the zonal arrangement of near-surface deposits suggest that deeper zones are well worth considering as exploration targets. [Resource potential—High]

MINERALIZED AREAS ASSOCIATED WITH LATE MIOCENE SILICIC ROCKS IN KINGSTON CANYON

A 5.4-Ma rhyolite volcanic center at Phonolite Hill in Kingston Canyon in the southeast part of the Richfield quadrangle (Area G, locality 38) is accompanied by locally altered wallrock. The altered rocks have been prospected for uranium and thorium, but no ore has been found. [Resource potential—Low]

MINERALIZED AREAS ASSOCIATED WITH PLIOCENE AND YOUNGER SILICIC ROCKS

Silicic volcanic rocks of Pliocene and early Pleistocene age (3–2 Ma) crop out in the Coyote Hills and Twin Peaks area 40–50 km north-northeast of Milford (Area H, figs. 3 and 4). Similar rocks of Pleistocene age (1–0.5 Ma) crop out in the central Mineral Mountains (Area I, figs. 3 and 4). A few anomalous metal values were obtained from scattered stream-sediment samples, but no well-defined areas showing evidence of significant hydrothermal activity were identified. [Resource potential—Low]

MINERALIZED AREAS NEAR COVE FORT AND SULPHURDALE

Modern solfataras and thermal springs are active in the Cove Fort-Sulphurdale area in the east-central part of the Richfield quadrangle, just east of a Pleistocene (0.5 Ma) basaltic andesite shield volcano (Area J, figs. 3 and 4). It is not known whether the thermal activity is related to the nearby mafic volcano, or to a hidden igneous body underlying the thermal area itself. The solfataras are manifested by areas of highly altered rock in which H_2S and SO_2 are presently being exhaled and native sulfur is being deposited. Sulfur is being produced from an open-pit mine at Sulphurdale (locality 39), and several presently inactive pits east (locality 40), northeast, and north of Cove Fort have produced sulfur in the past. One of the pits 2.5 km north of Cove Fort (locality 41) contains significant quantities of fluorite, and about 4,000 tonnes of fluorspar have been produced. Fluorite deposition clearly preceded modern sulfur deposition, but it is not known whether the fluorite formed early during the present mineralizing episode, or whether it is significantly older and was related to either the 9–Ma rhyolite of Gillies Hill to the south, or to the 3- to 2–Ma rhyolites in the Coyote Hills and Twin Peaks areas to the northwest. Present exposures of fluorite in the pit and adjacent areas are limited. [Resource potential—High to Moderate]

The thermal area and its associated solfataras has been classified as the Cove Fort KGRA (known geothermal resource area), and recent (1983) drilling has discovered steam near Sulphurdale. Geothermal resources are not within the scope of this report and will not be discussed further.

URANIUM IN BASIN FILLS

The Mount Belknap Volcanics and similar rhyolite accumulations in the bimodal mafic-silicic suite have been sources of large quantities of uranium freed by postdepositional diagenesis and solution. Much of this mobilized uranium entered the hydrologic regime and was transported to concurrently developing basins nearby. The ultimate sumps were the major alluviated structural troughs now marked by the Escalante and Sevier Deserts. The uranium content in the fill in at least some of these deeper basins may have been so diluted by water and sediments from barren terrains that the uranium was dispersed rather than concentrated. The water supplied to interim sumps nearer the uranium-bearing source rocks, however, may have had higher concentrations of uranium, which could have been precipitated by local reducing conditions within the complex basin fills.

Several late Cenozoic basin-fill deposits seem to have some possibility for containing secondarily deposited uranium. The fill in the Big John caldera (locality 42) consists of a blanket of conglomerate and sandstone underlying devitrified and zeolitized Joe Lott Tuff Member of the Mount Belknap Volcanics. The middle Miocene Sevier River Formation in the eastern part of the Richfield quadrangle was deposited in broad basins that show virtually no relation to the present distribution of horsts and grabens that constitute the High Plateaus. Thus, the configuration of the basins and the directions of flow of possible uranium-bearing surface and ground waters derived from the Mount Belknap Volcanics sources during Sevier River sedimentation undoubtedly were significantly different from those now in existence.

Beaver basin (locality 43) is a late Cenozoic structural basin filled by a complex sequence of stream and lake sediments; sedimentation began in middle or late Miocene and continued episodically until middle Pleistocene. The basin was drained for at least part of late Miocene time, but at other times it was closed and periodically contained lakes of varying size. The present outlet via Minersville Canyon was established in Pleistocene time. Highly anomalous concentrations of radon and helium have been detected at places in the basin, and geochemical samples of well waters strongly suggest the presence of uranium concentrations nearby. Preliminary drilling programs were conducted by several companies in the early 1980's, but no results have been made public.

Possible environments favorable for uranium deposition may also exist in basins adjacent to accumulations of Blawn Formation and Steamboat Mountain Formation in the southwestern part of the Richfield quadrangle. Well water samples have identified areas (localities 44 and 45) near Milford that are possibly proximal to uranium deposits and other areas in the Escalante Desert or in the southern parts of the Hamlin, Pine, and Wah Wah Valleys also may be favorable. [Resource potential—High in Beaver basin; Moderate in all other basins in southern part of Richfield quadrangle; Low in basins elsewhere in quadrangle]

UNCLASSIFIED MINERAL DEPOSITS

Some mineralized areas in the Richfield quadrangle cannot now be classified confidently with respect to geologic association. Such areas include scattered mines and prospects, local mineral occurrences, and scattered areas containing anomalous concentrations of several metallic elements.

The Gordon district (locality 46) in the southwestern Pavant Range contains the Blue Bell mine, which produced slightly more than 500 tonnes of silver-lead-zinc ore from small pod-shaped bodies consisting of smithsonite, hemimorphite, and minor cerussite and anglesite in a gangue of ocher, iron-stained calcite, sanded dolomite, and minor barite. The mineralized rock at the Blue Belle mine is remote from known centers of igneous activity, and its geologic association is not known. [Resource potential—Unknown]

The Fullmer clay pit (locality 47) along Mill Creek in the northern Tushar Mountains exploits a body of kaolinite formed by intense argillic alteration of the Joe Lott Tuff Member of the Mount Belknap Volcanics. Alteration was localized along an east-trending nearly vertical fault of unknown age. It is not known whether the isolated hydrothermal activity responsible for forming the kaolinite at the Fullmer pit took place late in the period of Mount Belknap magmatism, or during a younger and unrelated period. Lacking knowledge on the geologic association of the altered area, it is difficult to judge the potential at depth for other types of mineral deposits. [Resource potential—Unknown)

The Jarloose district (locality 48) in the northern Black Mountains has a few minor prospect pits and small mine workings scattered over an area of about 10 km^2. The prospects and altered rocks seem to be localized around an intrusive andesite plug that may mark the core of a local volcano in the Oligocene and Miocene Mount Dutton Formation. Little evidence was seen for significant mineral deposits in this area. [Resource potential—Low]

An area 8 km long east-west and as much as 2 km across in the northwestern part of the Black Mountains (locality 49) contains scattered areas of irregularly bleached and altered rocks. The more intensely argillized rocks were converted in part to alunite and kaolinite, and some rocks have been thoroughly silicified. Hematite, limonite, and pyrite are the only metallic minerals reported from the altered areas. (Resource potential—Low)

The laccolithic intrusive center near Spry in the southeastermost part of the Richfield quadrangle (locality 50) contains minor patches of altered and mineralized rock. Altered rocks near the northwest margin of the intrusions contain visible cinnabar, and some silver values and fluorite have been reported. These occurrences appear to be minor, and nowhere was evidence seen to suggest proximity to larger or more high-grade deposits. [Resource potential—Low]

A few minor prospects scattered throughout the Cricket Mountains were mostly dug on iron-stained calcite and dolomite with scattered concentrations of partly oxidized galena. The largest prospects are at the Galena mine and Rock Hammer mine, but neither has produced more than a few tonnes of ore. [Resource potential—Low]

Stream-sediment samples from the northwest part of the Richfield quadrangle disclosed widely scattered anomalous concentrations of many metallic elements. The different anomalous elements (As, Th, Zn, Bi, W, Mo, and Cu) are not coextensive, and no clear-cut local centers of hydrothermal activity have been identified. At the present time, we do not know the sources of the anomalous values obtained in this broad area, and thus are unable to assess their significance with respect to mineral resource potential. [Resource potential—Unknown]