Mineral Resources of the Arc Dome Wilderness Recommendation Area, Nye County, Nevada

U.S. GEOLOGICAL SURVEY BULLETIN 1961

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By GERALD F. BREM, DAVID A. JOHN, J. THOMAS NASH, FORREST G. POOLE, and DAVID B. SNYDER

An evaluation of the mineral resource potential of the area

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STUDIES RELATED TO WILDERNESS—
WILDERNESS RECOMMENDATION AREAS

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STUDIES RELATED TO WILDERNESS

United States Forest Service Wilderness Recommendation Area

Under the provisions of the Wilderness Act (Public Law 88-577, September 3, 1964) and related acts, the U.S. Geological Survey and the U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Studies of all primitive areas have been completed. Areas officially designated as "wilderness," "wild," or "canoe" when the act was passed were incorporated into the National Wilderness Preservation System, and some of them have been studied. The act provided that areas under consideration for wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. The act directs that the results of each survey are to be made available to the public and be submitted to the President and the Congress. This report discusses the results of a mineral survey of the Arc Dome Wilderness Recommendation Area (4-667), Toiyabe National Forest, Nye County, Nevada. The area was classified as a proposed wilderness during the Second Roadless Area Review and Evaluation (RARE II) by the Forest Service, January 1979. The Nevada Wilderness Protection Act of 1989 (S. 974) set aside 115,000 acres as the Arc Dome Wilderness, much of which is within the study area.

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PLATE
[In pocket]

FIGURES

Mineral Resources of the Arc Dome Wilderness Recommendation Area, Nye County, Nevada

By Gerald F. Brem, David A. John, J. Thomas Nash, Forrest G. Poole, *and* David B. Snyder

SUMMARY

Abstract

The Arc Dome Wilderness Recommendation Area (4-667) encompasses 94,000 acres (the study area) of the southern Toiyabe Range in northwestern Nye County west of Round Mountain, Nevada. The Nevada Wilderness Protection Act of 1989 (S. 974) set aside 115,000 acres as the Arc Dome Wilderness, much of which is within the study area. At the request of the U.S. Forest Service, geological, geochemical, and mineral surveys to assess the mineral resource potential of the study area were conducted by the U.S. Geological Survey between 1982 and 1985; results of studies completed in 1971 and 1981 have also been utilized. These studies indicate that one part of the study area has high mineral resource potential for tungsten and two areas have high potential for silver and (or) gold resources. Several other areas have moderate or low resource potential for silver and (or) gold with or without base metals (lead, zinc, copper, arsenic, and (or) antimony) or for placer gold. The study area has no resource potential for geothermal energy or for oil and gas. Areas having resource potential for tungsten, gold, silver, base metals, and geothermal energy outside but near the study area are also shown and discussed.

Character and Setting

The Arc Dome Wilderness Recommendation Area includes the most rugged part of the southern Toiyabe Range west of Round Mountain, Nev. (fig. 1). The precipitous eastern flank of the Toiyabe Range rises more than 5,500 feet from the floor of Big Smoky Valley and is cut by deeply incised drainages having spectacular cliffs and perennial streams. The moderate western slope is cut by less deeply incised drainages and perennial streams that drop nearly 5,000 ft to the Reese Valley. Highly deformed Late Proterozoic (presumedly) to Permian (see Geologic time chart in "Appendixes") marine clastic and carbonate rocks and volcanic rocks underlie much of the study area. These rocks and unconformably overlying Mesozoic silicified and altered tuffs were intruded by Jurassic, Cretaceous, and (or) Tertiary granitoid dikes and stocks. Oligocene and Miocene silicic ash-flow tuffs and other intermediate to silicic lava flows unconformably overlie all older rocks. Basalt of Tertiary and (or) Quaternary age and Quaternary surficial deposits are found in local areas within the mountains. The Toiyabe Range presently stands above alluvium-filled valleys because of relative uplift along late Tertiary and (or) Quaternary basin-and-range faults.

Mining activity has been intermittent in the southern Toiyabe Range since 1863 or 1864 when silver-lead-zinc ore was discovered (Kleinhampl and Ziony, 1984). All recorded production has been from mines outside the study area. Prior to 1890, production of silver and lead from the Murphy mine north of the study area (fig. 1) exceeded $755,000. Several tungsten mines east of the Murphy mine and north of the study area produced an estimated $500,000 worth of tungsten between 1950 and 1982. The Last Chance mine south of the study area produced more than 192 tons of antimony metal between 1915 and 1959. Nine mines or prospects within the study area produced unknown but presumably small amounts of gold, silver, lead, zinc, copper, and antimony from the 1860's to the 1950's. Most of them were one- or two-man operations that have no written records of production, but some were operated for many years. Many mines, claims, prospects, and mineralized areas were recognized within or adjacent to the study area, and 40 are shown on plate 1. Current mining activity within and adjacent to the study area is limited to prospecting and annual assessment work.

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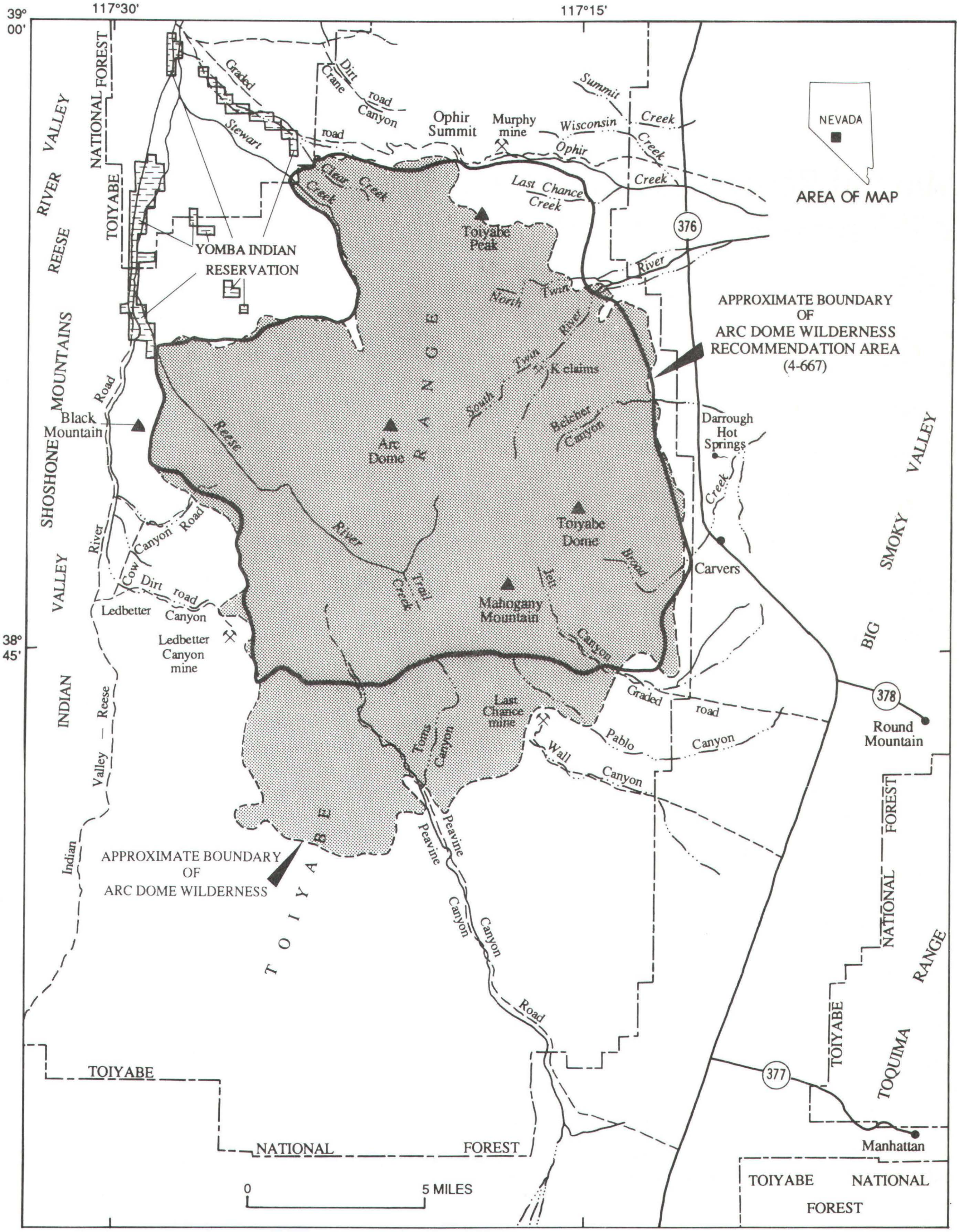

Figure 1. Index map showing location of Arc Dome Wilderness Recommendation Area (heavy line) and subsequent Arc Dome Wilderness (shaded area), Nye County, Nevada.

Mineral and Energy Resource Potential

Three types of metallic mineral occurrences have been recognized in the Arc Dome Wilderness Recommendation Area: (1) tungsten-bearing skarns; (2) polymetallic veins and disseminated minerals including silver, gold, lead, zinc, copper, arsenic, and (or) antimony; and (3) placer gold and silver. Geothermal energy resources are present east of the study area but do not extend into it. Oil and gas have not been found in or near the study area. Barite, limestone, dolostone, and dimension stone are locally present in or near the study area.

Tungsten-bearing skarn is present north and west of the granitic pluton in the northeast corner of the study area (pl. 1; fig. 2). These skarns are restricted to contacts between sedimentary rocks and the Ophir pluton. Tungsten minerals occur primarily in quartz- and-scheelite-bearing shear zones that cut skarn. Although the principal tungsten production has been north of the study area along the north side of Ophir Creek, geologic data and stream-sediment geochemical anomalies of tungsten and bismuth suggest that skarn possibly containing tungsten minerals extends into the study area south of Ophir Creek along the west side of the Ophir pluton. This area and one north of it have high mineral resource potential for tungsten. One area southeast of the study area has moderate resource potential for tungsten in skarn adjacent to a granite porphyry dike.

Polymetallic veins and some disseminated minerals are present in five general areas at least partly within the study area and in several other areas outside but near the study area. Typically, quartz and calcite veins that are a few inches to 12 ft wide include narrower ore zones that locally contain silver, gold, lead, zinc, copper, arsenic, and (or) antimony. Precious and base metals occur in three geologic environments within the study area: (1) veins or disseminated minerals in Late Proterozoic and Paleozoic rocks near Mesozoic plutonic rocks; (2) veins in Late Proterozoic and Paleozoic sedimentary rocks or Mesozoic volcanic rocks near granite porphyry; and (3) veins in or below Tertiary tuffs. The mineral resource potential is high for gold near Mesozoic plutons in one area south of the Murphy mine and for gold and silver near granite porphyry at the K claims (fig. 2). The mineral resource potential for silver, gold, lead, zinc, and copper, with or without antimony, is high near the Murphy mine and is moderate in two areas near it. An area east of the K claims has low resource potential for gold and silver. An area in the south-central part of the study area has moderate and low potential for gold in or below Tertiary volcanic rocks. Another area near the center of the study area has low potential for polymetallic veins in the same setting. Irregular areas in the east-central part of the study area have moderate or low potential for polymetallic mineral resources near granite porphyry. Although a broad area on the west side of the study area has stream-sediment geochemical anomalies suggestive of polymetallic mineralization, the rocks upstream are not recognizably altered or mineralized; thus, the area is assigned only low resource potential for polymetallic minerals in or below Tertiary rocks. The southeast corner of the study area has low resource potential for silver, gold, lead, zinc, and copper near granite porphyry. South of the study area the mineral resource potential for antimony and silver is high at the Last Chance mine and low near it. Several other areas north, west, and south of the study area also have high, moderate, or low resource potential for base and (or) precious metals.

Placer gold and silver deposits are present or have been prospected for in three areas. Placer gold and silver deposits at the mouth of Ophir Creek and placer gold deposits at Crane Canyon are outside the study area but may have been derived from bedrock sources partly within the study area. The mineral resource potential is low for placer gold and silver at the former area and is low for in situ gold at the latter area. The resource potential is moderate for placer gold in Trail Creek near its junction with Reese River.

Geothermal energy resources occur in the Darrough Hot Springs Known Geothermal Resource Area east of the study area. Although the resource potential for geothermal energy there is high, it probably is restricted to valley fill east of a fault in Big Smoky Valley and does not extend into the study area.

No oil and gas have been discovered in or near the study area, and there is no resource potential for oil and gas.

Areas of barite, limestone, dolostone, and dimension stone are locally exposed in or adjacent to the eastern part of the study area, but we do not assign them any resource potential.

INTRODUCTION

This mineral survey was requested by the U.S. Forest Service and is a joint effort by the U.S. Geological Survey and the U.S. Bureau of Mines. An introduction to the wilderness review process, mineral survey methods, and agency responsibilities was provided by Beikman and others (1983). The U.S. Bureau of Mines evaluates identified resources at individual mines and known mineralized areas by collecting data on current and past mining activities and through field examination of mines, prospects, claims, and mineralized areas. Results of the U.S. Bureau of Mines study were published separately (Johnson and others, 1989). Studies by the U.S. Geological Survey are designed to provide a reasonable scientific basis for assessing the potential for undiscovered mineral resources by determining geologic

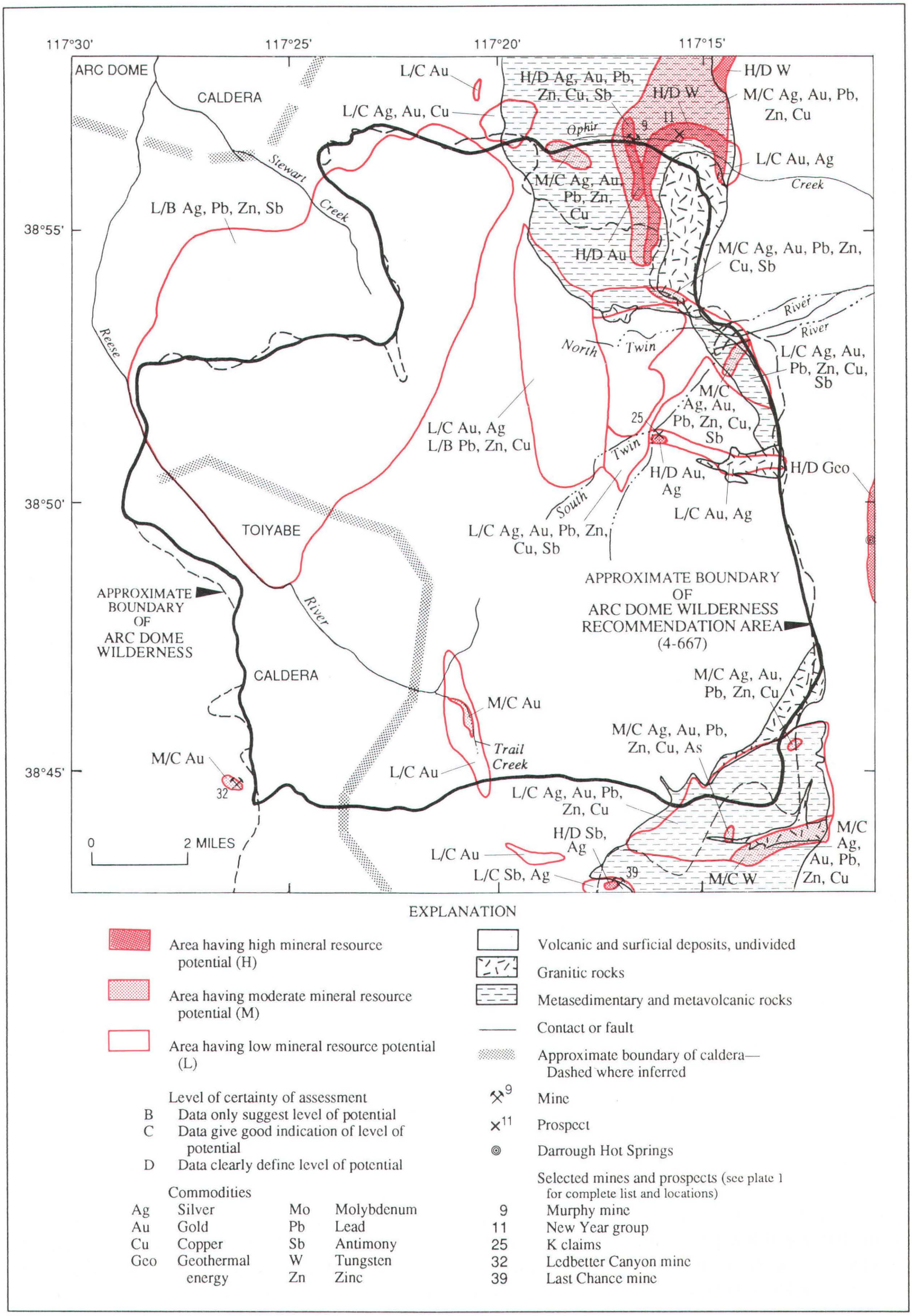

Figure 2. Mineral resource potential and generalized rock types of Arc Dome Wilderness Recommendation Area, Nye County, Nevada.

units and structures, possible environments of mineral deposition, presence of geochemical and geophysical anomalies, and applicable ore-deposit models. Mineral assessment methodology and terminology as they apply to these surveys were discussed by Goudarzi (1984). See "Appendix" for the definition of levels of mineral resource potential and certainty of assessment.

Area Description

The Arc Dome Wilderness Recommendation Area (4-667) covers 94,000 acres in the southern Toiyabe Range between the Big Smoky and Reese River Valleys in west-central Nevada (fig. 1). The Nevada Wilderness Protection Act of 1989 (S. 974) set aside 115,000 acres as the Arc Dome Wilderness, much of which is within the study area. The terrain is rugged. Vertical relief is great, rising from approximately 6,200 ft above sea level at the base of the range on the east margin of the study area in Big Smoky Valley to 11,773 ft at the summit of Arc Dome. The eastern escarpment of the range is extremely rugged, rising some 4,500 ft in as little as 3 mi. East-flowing streams are deeply incised into this fault-produced escarpment. The western slope of the range is less precipitous, dropping from the crest of the range down to the Reese River Valley at approximately 6,800 ft. The western slope of the range is incised by a number of northwest-flowing streams including the upper drainages of Reese River.

The climate is semiarid, and vegetation ranges from sparse to dense. Valley floors are sparsely to moderately vegetated with sagebrush, rabbit brush, grasses, and annuals. Above 6,200 ft, slopes are covered by a dense juniper-pinyon forest that gradually grades upward into patchy mountain mahogany above about 8,700 ft. Sparsely vegetated ground between patches of mountain mahogany support dwarfed sagebrush and annuals; small stands of whitebark pine occur near the crest of the range and on north-facing canyon walls. Perennial vegetation along streams includes cottonwood, aspen, water birch, wild rose, willow, chokecherry, and elderberry in deep canyons and grasses in the few mountain meadows.

Access to most of the study area is limited to foot trails that start at the end of dirt roads. Nevada State Highway 376 runs along Big Smoky Valley, and numerous graded and unimproved dirt roads lead from it to the eastern base of the range. The north side of the study area is bounded by a graded dirt road that follows Ophir Creek westward from the State highway, crosses the range, and follows Clear Creek down to the Reese River Valley. A graded dirt road along Reese River Valley continues into Indian Valley, and several graded and ungraded roads extend eastward from it to the west edge of the study area. Graded dirt roads that follow Jett, Wall, Peavine, and Toms Canyons provide access to trail heads at the south edge of the area. Well-maintained Forest Service trails course through the canyons of most major drainages. The Toiyabe Summit Trail extends southward along the range crest from Ophir Summit into the drainages of North and South Twin Rivers and Reese River. An improved mine road from the mouth of South Twin River to the K claims in the South Fork of South Twin River was washed out in 1983.

Previous and Present Investigations

The Arc Dome Wilderness Recommendation Area includes all or part of the Corral Wash, Toiyabe Peak, Carvers NW, Bakeoven Creek, Arc Dome, Carvers, Farrington Canyon, Toms Canyon, and Pablo Canyon Ranch 7.5-minute quadrangles, which were composited and reduced to create the topographic base used for plate 1. Ferguson and Cathcart (1954) published the first geologic map of the Arc Dome area at a scale of 1:125,000. Kleinhampl and Ziony (1985) modified the map of Ferguson and Cathcart, primarily by remapping some of the pre-Tertiary units and compiling all mapping on a modern topographic base at a scale of 1:250,000. Almost all of the Arc Dome area has been remapped but not yet published at a scale of 1:62,500 or larger by G.F. Brem (Darrough Felsite, granite porphyry, Tertiary volcanic rocks, and surficial units), F.G. Poole (Late Proterozoic and Paleozoic rocks), and D.A. John (Mesozoic plutonic rocks); plate 1 is based on that unpublished mapping.

The first published reports for the area were about mining activity centered in the Ophir Creek area in the 1860's and 1870's (summarized in Kleinhampl and Ziony, 1984). Ferguson and Muller (1949) described some of the structure in the eastern Toiyabe Range. Kral (1951) and Lawrence (1963) described many of the mineral occurrences in the southern Toiyabe Range. Means (1962) described pre-Tertiary units north of the study area, and Speed and coworkers (Speed and MacMillan, 1972; Speed, 1977; Speed and others, 1977) and Poole and coworkers (Poole and Wardlaw, 1978; Poole and Jones, 1979; F.G. Poole, unpub. data, 1985) have studied the complex pre-Tertiary geology in and around the study area. Poole and Desborough (1973) described serpentinites in the southern Toiyabe Range and elsewhere in Nevada and discussed their regional tectonic significance. Speed and McKee (1976) described and reported radiometric dates for the Darrough Felsite. Garside and Schilling (1979) described geothermal energy resources in the Darrough Hot Springs Known Geothermal Resource Area. Kleinhampl and Ziony (1984, 1985) described rock units, geologic history, and mineral occurrences in the southern Toiyabe Range. Brem and coworkers (Brem and Snyder, 1983; Brem and others,

1985) described Tertiary volcanic and tectonic features in the southern Toiyabe Range. John (1987), John and McKee (1987), and John and Robinson (1989) described granitic rocks in the Tonopah 1° by 2° quadrangle and reported radiometric ages for several plutons. Nash (1988) and Nash and Siems (1988) reported and interpreted analytical results of stream-sediment samples collected in the study area as part of a larger study of the Tonopah 1° by 2° quadrangle. Johnson and others (1989) described the identified (known) mineral resources of the Arc Dome study area. John (in press) describes the stratigraphy, distribution, petrography, and geochemistry of several Tertiary ash-flow tuff units present in the study area.

The U.S. Geological Survey carried out field work for this study during the summers of 1982–85; however, data from studies published in 1971 and 1981 (U.S. Geological Survey, 1971; Healey and others, 1981) are also used in this report. The work included field mapping, petrographic and paleontologic studies, geochemical sampling, and aeromagnetic and gravity surveys. A detailed geologic map of the area was assembled (G.F. Brem, F.G. Poole, and D.A. John, unpub. data, 1985). Rock samples from selected mines and areas of alteration were collected and chemically analyzed to obtain information about mineral suites and trace-element signatures associated with areas known to have been mineralized. Stream-sediment and panned heavy-mineral-concentrate samples were collected from 91 sites and chemically analyzed to further define and characterize known mineralized areas and to identify previously unrecognized mineralized areas (Fairfield and others, 1985; Siems and others, 1986; Nash, 1988; Nash and Siems, 1988). Gravity surveys were conducted to identify major gravity anomalies and to delineate tectonic and volcanic boundaries that are relevant to mineral-deposit models (Healey and others, 1981; Snyder and Healey, 1983; Brem and others, 1985). Aeromagnetic surveys (U.S. Geological Survey, 1971; Plouff, 1990) were analyzed to identify major magnetic anomalies that may be related to mineral deposits. On the basis of these studies, areas of identified (known) resources were assessed, and other areas within and near the Arc Dome study area were assessed for the possibility of any potential (unidentified) mineral and energy resources.

Geologic Setting

The Arc Dome Wilderness Recommendation Area in west-central Nevada is within the Basin and Range province. Many of the rock units, structures, and mineral deposits within the study area are comparable to features within nearby parts of Nevada and east-central California. Clastic and carbonate marine sedimentary rocks and volcanic rocks of Late Proterozoic to Permian age are highly deformed as a result of Paleozoic and Mesozoic orogenic events. These deformed rocks are structurally and depositionally overlain by the Darrough Felsite, a silicified and metamorphosed, dominantly pyroclastic unit of probable Mesozoic age. The sedimentary and pyroclastic rocks were multiply intruded by Cretaceous plutons. These plutons are similar in composition and texture to those that were emplaced in the Mesozoic magmatic arc of western Nevada and eastern California. The plutons and all older rocks were intruded by granite porphyry dikes and stocks during latest Cretaceous or Tertiary time and by diabase dikes in Tertiary time. Oligocene to lower Miocene silicic ash-flow tuffs interbedded with less abundant lava flows of intermediate to silicic composition unconformably overlie the older rocks. The volcanic rocks were erupted from extrusive centers in adjacent ranges and from three volcanic centers in the Peavine Canyon, Black Mountain, and Reese River Valley areas south of, in, and northwest of the study area, respectively. All of these rocks, as well as older structures, were cut by late Tertiary and (or) Quaternary north- to northeast-trending faults that resulted in the formation of Basin and Range physiography.

APPRAISAL OF IDENTIFIED RESOURCES

History and Production

The study area encompasses three mining districts as defined by Kleinhampl and Ziony (1984). The Twin River mining district extends southward along both sides of the Toiyabe Range from north of the study area to South Twin and Reese Rivers. The Jett mining district lies southeast of South Twin River and east of Peavine Canyon. The Cloverdale mining district, south of the Twin River district and west of the Jett district, encompasses the southwestern Toiyabe Range and southern Shoshone Mountains.

The first discovery of ore in the vicinity of the study area was in 1863 or 1864 on the Murphy vein in Ophir Creek canyon (Kleinhampl and Ziony, 1984). The Murphy mine (also known as Ophir; No. 9 on pl. 1) was opened in 1866; by its first closing in 1869 it had produced an estimated $700,000 worth of ore, principally silver and gold (Kral, 1951). Recorded production from 1875 to 1890 was valued at nearly $55,000 (Couch and Carpenter, 1943), although there are unconfirmed reports of more production (Kleinhampl and Ziony, 1984). Exploration and development of small mines undoubtedly took place during this time interval, but there are no records of their production.

The Last Chance mine (also known as Wall Canyon; No. 39, pl. 1) south of the study area was located and began production in 1915. Intermittent activity until 1959 resulted in production of 192 tons of antimony metal as well as minor amounts of silver (Lawrence, 1963). A few mines or prospects adjacent to the study area, such as the Gruss (No. 7), Ledbetter Canyon (No. 32), Valley Group (No. 34), and others along Ophir Creek and Jett Canyon were located or worked between 1917 and the 1960's; however, no production is known other than the processing of 400 tons of ore of unknown grade from the Ledbetter Canyon mine in 1932 and 6.5 tons of rich lead, zinc, copper, arsenic, silver, and gold ore from the Valley Group in 1948 (Kral, 1951). Mines and prospects within the study area, such as the Dallimore-Douglas (No. 8), Grizzly (No. 10), Korf (No. 18), Teichert (No. 21), and K claims (No. 25), may have produced small amounts of ore that were not recorded (R.E. Wilson, a local claim holder, oral commun., 1985).

Tungsten minerals were mined from a number of mines along the north wall of Ophir Creek canyon in the 1950's and early 1960's during the Federal Government's price-support program and in 1974 and 1982. Tungsten ore was mined from calc-silicate skarns near the contact of the Ophir pluton with Late Proterozoic and Paleozoic rocks. Mineralized rocks parallel Ophir Creek from about 1 mi east of the Murphy mine to the range front. The western group of these claims and mines in the canyon (No. 11, pl. 1), variously referred to as the New Year group, Bobby Bottoms mine, Warfield(?), and Loring, produced an unknown amount of tungsten ore in the 1960's and ore valued at about $29,000 in 1974 (R.E. Wilson, oral commun., 1985). The eastern group of these claims and mines (includes the Bobby No. 4 mine; no. 12, pl. 1), near the range front, produced tungsten ore valued at about $150,000 from 1952–54 (Kleinhampl and Ziony, 1984), at $38,000 in 1956 (R.E. Wilson, oral commun., 1985), and an unknown amount in 1982. The total value of tungsten production from this area and from a small mine north of the mouth of Wisconsin Creek (No. 14) may have been nearly $500,000, although records are incomplete (Kleinhampl and Ziony, 1984).

Mineral and Energy Occurrences

Tungsten, base metals (lead, zinc, copper, antimony), precious metals (gold, silver), geothermal energy, and industrial minerals occur in and (or) near the study area. Some mines and prospects were visited and evaluated in 1984 and 1985 by the U.S. Geological Survey. Mines and prospects that were not accessible or were not visited are interpreted here by using descriptions of mineral occurrences by Kral (1951), Lawrence (1963), and Kleinhampl and Ziony (1984) to infer the character and extent of mineralized rock and to evaluate the resource potential. Other published reports listed in Kleinhampl and Ziony (1984) and geochemical data (Fairfield and others, 1985; Siems and others, 1986; Nash, 1988; Nash and Siems, 1988) were also used to evaluate the nature of the mineral occurrences and their resource potential. Resource descriptions and assessments of Sandberg (1983) and Garside and Schilling (1979) were used for oil and gas and for geothermal energy resource assessments, respectively.

Three types of metallic mineral occurrences have been recognized in and near the Arc Dome Wilderness Recommendation Area: (1) tungsten-bearing calc-silicate skarns; (2) polymetallic (silver, gold, lead, zinc, copper, arsenic, antimony) veins and disseminated minerals; and (3) gold and silver placer deposits.

Tungsten Skarns

Tungsten-bearing calc-silicate skarns are present in Late Proterozoic and Paleozoic rocks near the contact with the Ophir pluton on the canyon wall north of Ophir Creek (Nos. 11, 12, pl. 1) and the contact with Aiken Creek pluton north of Wisconsin Creek (No. 14). Skarn mineralization appears to be restricted to carbonate rocks. Tungsten minerals are locally disseminated in skarn but more typically occur in quartz-veined shear zones within the skarn (Kleinhampl and Ziony, 1984). Quartz veins having scheelite and minor molybdenite and pyrite can be traced for as much as 500 ft along strike. Tungsten minerals are typically concentrated in zones as wide as 10 ft (R.E. Wilson, oral commun., 1985), and tungsten contents range from 0.1 to 5.0 percent tungsten trioxide (Kleinhampl and Ziony, 1984). Tungsten minerals also may occur in quartz-feldspar-muscovite pegmatite dikes and sills in Ophir Creek canyon adjacent to the Ophir pluton (F.G. Poole, unpub. data, 1985). The relation of tungsten minerals in dikes and sills to those in skarn is unknown. The results of prospecting for tungsten minerals in quartz veins of the White Horse prospect (No. 17, pl. 1; Kleinhampl and Ziony, 1984) and in silicified rock along an edge of a granite porphyry dike in Jett Canyon (No. 35) are unknown.

Polymetallic Veins

Polymetallic veins and disseminated minerals occur in more than three-quarters of the mines and prospects in and near the study area. Available geologic and geochemical data suggest that polymetallic veins and disseminated minerals vary considerably in composition and age; however, the data are insufficient to allow distinction between various types of deposits of different ages. Their compositions apparently range continuously from base metal to precious metal. Their spatial associations with rocks of different ages suggest that separate mineralization events may have followed intrusion of Mesozoic plutons, intrusion of Late Cretaceous and (or) Tertiary granite porphyry, and eruption of Tertiary tuffs. It is also possible that minerals deposited in one mineralization event have been remobilized in subsequent events, such as in the Toquima Range to the east (Shawe and others, 1986). These polymetallic veins and disseminated minerals can be grouped on the basis of geologic environment, which includes host-rock type and spatially associated rocks. All mineralized areas within a group, however, do not necessarily have a similar genesis or age of formation. Polymetallic veins and disseminated minerals are present in three geologic environments in the study area: (1) veins and disseminated minerals in Late Proterozoic and Paleozoic rocks spatially associated with Mesozoic plutonic rocks; (2) veins in sedimentary and volcanic rocks associated with granite porphyry dikes and stocks; and (3) veins in or below Tertiary volcanic rocks.

Polymetallic veins and disseminated minerals in Late Proterozoic and Paleozoic rocks are spatially associated with the Ophir and Ophir Summit plutons in and north of the study area (Nos. 2, 7–10, 13, 17, and 18; pl. 1); of these sites, only the Gruss mine (No. 7) was visited. Typically, these mineral occurrences contain base metals (primarily lead, zinc, copper, antimony), silver, and gold; however, some contain mostly gold. The mineralized areas generally consist of quartz- and calcite-bearing veins along well-developed shears or fractures. Veins range in width from a few inches to 12 ft; metal-bearing zones are narrower. Veins are generally not continuous for more than a few hundred feet (425 ft at the Murphy mine, No. 9, according to Hague, 1870, for example). The veins are relatively short because mineralization is generally restricted to calcareous parts of highly deformed host rocks. In the Wisconsin Creek area, ore minerals are disseminated within a broad brecciated and silicified zone. In other areas, host rocks are silicified near veins but otherwise are little altered. Sulfide minerals typically are pyrite, argentiferous galena, sphalerite, stibnite, and tetrahedrite. Pyrargyrite, native silver, and silver chloride occurred in the Murphy mine (No. 9), and gold was observed in the Grizzly, White Horse, and Korf properties (Nos. 10, 17, and 18; Kleinhampl and Ziony, 1984). The Grizzly prospect (No. 10) was worked for 40 years by a single operator (R.E. Wilson, oral commun., 1985), and the Korf mine (No. 18) supported a single operator prior to 1930 (Kral, 1951). The White Horse prospect (No. 17) contains narrow high-grade gold veins yielding reported assays of $3 to $245 per ton (Kral, 1951).

Polymetallic veins having base metals and silver occur in Late Proterozoic and Paleozoic rocks near granite porphyry or in the granite porphyry. All mineralized areas of these rocks, except those high on the south side of Jett Canyon, were visited in 1985. Mineralized Late Proterozoic and Paleozoic rocks are present in and adjacent to the eastern and southeastern parts of the study area (Nos. 21, 23, 24, 31, 33–37, and 39; pl. 1). Typically, the mineralized zones consist of quartz- and (or) calcite-bearing veins or anastomosing veinlets a few inches to 3 ft wide along shear zones or faults. Mineralized veins or zones of veinlets can be traced at most for a few hundred feet along strike, where they either pinch out or are terminated by faults. Late Proterozoic and Paleozoic rocks are silicified or bleached next to the veins, whereas granite porphyry is partly replaced by chlorite or carbonate minerals. Vuggy and brecciated gangue minerals have textures indicative of multiphase brecciation. Rock samples from veins contain silver, gold, copper, lead, antimony, bismuth, and zinc, as do stream-sediment samples in drainages below vein outcrops. Metallic minerals include minor to abundant argentiferous galena, sphalerite, and pyrite, variable amounts of tetrahedrite, chalcopyrite, bornite, and stibnite, and secondary minerals.

Polymetallic veins in the Darrough Felsite and associated with the granite porphyry are present in and near the eastern and southern parts of the study area (Nos. 25, 26, 29, and 38; pl. 1), and all except No. 38 were visited in 1985. The mineralized areas are similar in width and length to those in Late Proterozoic and Paleozoic rocks; however, in the K claims (No. 25) in the South Fork of South Twin River, a zone of anastomosing veinlets several hundred feet long is as much as 5 ft wide, and a zone of pyritized, argillized, and locally silicified rock east of the K claims near the contact of granite porphyry with the Darrough Felsite can be traced discontinuously for more than 2 mi. At the K claims, brecciated and vuggy quartz gangue contains pyrite as the only recognizable sulfide mineral; chemical analyses show that the gold is associated with clay minerals. Sampling of the vein indicates an average assay of 0.25 troy oz gold and 0.4 troy oz silver per ton; local concentrations are as high as 2.1 oz gold and 6.6 oz silver per ton (James Voss, U.S. Forest Service, unpub. data, 1979). In the area near Trail Creek canyon, native gold has been recovered from placer deposits below mineralized outcrops of the Darrough Felsite.

Polymetallic veins in Tertiary volcanic rocks or the underlying Late Proterozoic and Paleozoic rocks are present west of Ophir Summit (Nos. 3–6, pl. 1), in the middle drainages of North Twin River and North Fork of South Twin River and along the Reese River near Trail Creek canyon (Nos. 19, 20, 22, 27, 28, and 30), and at the Ledbetter Canyon mine (No. 32) just west of the study area. The properties in North Twin River, North Fork of South Twin River, and Ledbetter Canyon were not examined; the others were examined in 1984 and

1985. Typically, these mineralized areas contain precious metals, but stream-sediment geochemical anomalies indicate that base-metal sulfide minerals may also be present.

The physical and mineralogical characteristics of mineralized areas in Tertiary rocks vary. In a broad zone of tuff and underlying pre-Tertiary rocks between Ophir Summit and Crane Canyon creek, closely spaced shear zones are silicified and contain pyrite and minor secondary copper minerals. In the Twin Rivers area, tuffs are weakly argillized and silicified and contain narrow silicified fractures. In the Trail Creek–Reese River area, a broad zone of tuff is argillized and locally silicified; associated rhyolite is locally silicified and pyritized, and native gold is present. At the Ledbetter Canyon mine (No. 32), the mineralized area consists of a quartz-bearing vein several feet wide (Kral, 1951).

Stream-sediment samples collected from drainages in Tertiary tuffs on the west side of the range between Reese River and Clear Creek contain anomalous amounts of a suite of elements that are tentatively related to polymetallic vein mineralization, although no mineralized areas were recognized during geologic mapping.

Placer Gold and Silver

Placer gold and (or) silver deposits have been found in alluvial deposits at the mouths of Ophir Creek and Crane Canyon outside the study area (Nos. 1 and 16, pl. 1) and in Trail Creek canyon near its junction with Reese River in the south-central part of the study area (No. 29). Little is known about occurrences near Ophir Creek and Crane Canyon other than the reported presence of precious metals (Kleinhampl and Ziony, 1984) and the occurrence of gold and silver in bedrock upstream from the sites. Unknown amounts of fine-grained placer gold have been recovered from Trail Creek in several one-man placer operations during the past 30 years (E.M. Tomany, a local prospector, oral commun., 1985).

Energy Resources

The Darrough Hot Springs Known Geothermal Resource Area (KGRA) is in Big Smoky Valley east of the study area (fig. 2; No. 40, pl. 1). Geothermal energy resources are present in Big Smoky Valley as far as 15 miles north of Darrough Hot Springs. The KGRA is marked by a series of flowing springs that discharge as much as several hundred gallons of water per minute at surface temperatures as high as 97 °C (Garside and Schilling, 1979). An 812-foot-deep well, drilled in 1962 and redrilled in 1963, encountered bottom-hole temperatures of 265 °C. Several chemical geothermometers indicate a reservoir temperature of 200–275 °C.

No oil or gas discoveries have been made in or adjacent to the study area.

Industrial Minerals

Barite, limestone, dolostone, and dimension stone are present in or near the study area. Bedded barite has been mined from a property north of the study area (Kleinhampl and Ziony, 1984). Devonian rocks in the adjacent Toquima Range contain bedded barite (Shawe and others, 1967, 1969; Poole and Sandberg, 1975). Although Devonian rocks are exposed in the study area, barite has not been recognized in them. Limestone was quarried from Late Proterozoic and Paleozoic rocks near the mouth of Wisconsin Creek canyon (No. 15, pl. 1) for the manufacture of lime. Both limestone and dolostone occur as discontinuous lenses or beds in highly deformed Late Proterozoic and Paleozoic rocks. Dimension stone for the construction of local homes and mills was collected or quarried from talus or outcrops northeast of the study area (Kleinhampl and Ziony, 1984).

ASSESSMENT OF MINERAL AND ENERGY RESOURCE POTENTIAL

Geology

Late Proterozoic and Paleozoic rocks

Presumedly Late Proterozoic and Paleozoic sedimentary and volcanic rocks crop out in the northern, northeastern, and southeastern parts of the study area. The multiply deformed and variably metamorphosed rocks can be subdivided into four stratigraphic and (or) structural packages. Although described individually below, these rocks have been combined into a single unit on plate 1 because of the map scale and because mapping is incomplete. Late Proterozoic and Paleozoic rocks, especially calcareous sedimentary facies, are the principal host rocks for tungsten-bearing skarns and for polymetallic veins and disseminated minerals.

Late Proterozoic to Silurian parautochthonous rocks.—This nearly autochthonous sequence of rocks includes Late Proterozoic to Middle Cambrian argillite, siltstone, quartzite, grit, and sparse limestone or dolostone. Overlying the Middle Cambrian clastic rocks is a unit of Upper Cambrian(?) and Ordovician argillite and siltstone with interbedded quartzite and limestone. Locally, Silurian dolostone and silty limestone to limy siltstone conformably overlie the Ordovician strata.

Lower Cambrian allochthonous rocks.—These easterly transported allochthonous rocks are thrust over the Late Proterozoic to Silurian rocks and consist of argillite, siltstone, and minor quartzite and limestone or dolostone.

Pennsylvanian and Permian parautochthonous rocks.—These parautochthonous rocks rest unconformably on older rocks in some outcrops, but in most outcrops they rest in thrust contact on older rocks. They are composed of argillite, siltstone, quartzite, grit, limestone, and conglomerates whose clasts are similar to the underlying Cambrian and Ordovician rocks. Locally, greenstone and serpentinite clasts occur in conglomerate beds in the lower part of the assemblage, and alpine-type serpentinite bodies have been mapped at or just below the basal contact of the assemblage.

Mississippian to Permian allochthonous rocks.—These easterly transported allochthonous eugeosynclinal rocks are thrust over the other Late Proterozoic and Paleozoic rocks. The assemblage consists of argillite, siltstone, chert, greenstone (pillow lavas), and minor quartzite and conglomerate. This allochthon is the structurally highest thrust plate exposed in the study area.

Cretaceous and (or) older felsite

The Darrough Felsite unconformably overlies or is in fault contact with Late Proterozoic and Paleozoic rocks in the eastern and southern parts of the study area. The unit consists mainly of silicified and variably metamorphosed silicic ash-flow tuffs and volcaniclastic sedimentary rocks. Andesite, which is not separated from the felsite on the map (pl. 1), intruded and presumably overlies the silicic rocks south of Toiyabe Dome. Although Oligocene and Miocene isotopic ages have been reported on the Darrough Felsite (Speed and McKee, 1976), we infer that the Darrough Felsite is Cretaceous and (or) older in age because near the mouth of North Twin River it appears to be intruded by the main phase of the Ophir pluton, whose age is Late Cretaceous (approx. 89 Ma; John and Robinson, 1989). The Tertiary potassium-argon ages reported by Speed and McKee (1974) may have been reset by Tertiary igneous activity.

Mesozoic granitic rocks

The Ophir pluton in the northeast corner of the study area intruded Late Proterozoic and Paleozoic rocks and apparently intruded the Darrough Felsite. This composite pluton consists of at least four intrusive phases that include, from oldest to youngest, gneissic biotite granodiorite (main phase), garnet-muscovite (biotite) granite, biotite-hornblende quartz diorite, and biotite granodiorite (John, 1987). Tungsten-bearing calc-silicate skarns occur near the contact of the oldest pluton with Late Proterozoic and Paleozoic rocks. Although Speed and McKee (1976) report an isotopic age of 53.9±1.5 Ma on one of the younger phases of the composite pluton, that age may be thermally reset, and we consider the pluton to be Late Cretaceous in age. A whole-rock rubidium-strontium isochron on the main phase suggests a minimum age of 89.1±8.7 Ma (John and Robinson, 1989). A minimum age of Late Cretaceous also is suggested by a potassium-argon age of approximately 69.5±1.7 Ma on muscovite in a late-stage altered part of the skarn (Marvin and Dobson, 1979).

The Late Proterozoic and Paleozoic rocks were intruded by dioritic dikes and stocks along a fault west of Ophir Summit and by a granodioritic stock east of the summit. Kleinhampl and Ziony (1985) consider these plutons to be of Jurassic and (or) Cretaceous age; their age relations to the Darrough Felsite and the Ophir pluton are unknown.

Cretaceous and (or) Tertiary intrusive rocks

Granite porphyry dikes, sills, and stocks intruded upper Paleozoic to Cretaceous rocks in the eastern third of the study area. Many of the intrusions were emplaced along faults. The porphyry has a very fine grained felsic groundmass that commonly contains phenocrysts of potassium feldspar, plagioclase, quartz, and locally biotite and hornblende. Polymetallic veins are closely associated with or are within the porphyry. Speed and McKee (1976) reported an Oligocene (29.4±0.8 Ma) potassium-argon age on the dike in Broad Creek canyon, and a similar dike north of Belcher Canyon also has an Oligocene age (26.5±0.9 Ma; Marvin and others, 1989). However, we consider these radiometric ages to be thermally reset ages, and the age of the granite porphyry may actually be Late Cretaceous or early Tertiary.

Granite porphyry and older rocks were intruded by diabase dikes that are too small to show on plate 1. These north-trending dikes, ranging from 1 to 15 m in width, do not appear to be associated with mineralized rocks.

Oligocene and lower Miocene volcanic rocks

Upper Oligocene to lower Miocene volcanic rocks, dominantly silicic ash-flow tuffs, unconformably overlie all older units. Most of the volcanic rocks crop out in the western two-thirds of the study area, west of a major fault in Jett Canyon and the South Fork of South Twin River Canyon (pl. 1). The age of the oldest unit is uncertain but is presumed to be late Oligocene, whereas the youngest unit, the basaltic andesite of Ledbetter Canyon, is early Miocene (17.1±0.5 Ma; McKee and John, 1987).

The older tuffs crop out in the southern part of the study area between the upper Reese River and Jett Canyon. These ash-flow tuffs overlie the Darrough Felsite and are less altered than the Darrough. Most of these tuffs are crystal-rich quartz latites whose crystal contents range from 25 to 40 percent. Included within the unit are rhyolite flows and intrusions in the lower part of the sequence. The only tuff of local origin is a crystal-poor and lithic-rich tuff derived from the Peavine volcanic center south of the study area (Brem and Snyder, 1983).

The conformably overlying tuffs of North Fork are widely exposed between Reese River and North Twin River. The oldest and thickest part of the unit is a crystal-poor to moderately crystal rich, densely welded ash-flow tuff that is locally zeolitized or silicified. Volcaniclastic sedimentary rocks, biotite-bearing lapilli tuff, and a crystal-poor lithic tuff conformably overlie the lower part of the unit.

The tuff of Arc Dome crops out throughout the northwestern part of the study area. This tuff conformably overlies the tuffs of North Fork north of Reese River but is not exposed south of the river. This crystal-rich, densely welded rhyolitic ash-flow tuff is characterized by distinctive bipyramidal smoky quartz phenocrysts. The tuff may have been derived from a volcanic center northwest of the study area (pl. 1) that is inferred on the basis of increasing unit thickness, lithologic diversity, hydrothermal alteration, negative gravity anomaly, and the presence of dikes and rhyolite domes in the Clear Creek and Crane Canyon areas. Those dikes and domes are mapped as part of the tuff of Arc Dome on plate 1.

The tuff of Toiyabe unconformably overlies the tuff of Arc Dome and crops out mainly in the southwestern part of the study area. It is equivalent, in part, to the Toiyabe Quartz Latite of former usage as mapped by Ferguson and Cathcart (1954) and Kleinhampl and Ziony (1985). John (in press) discusses the stratigraphic relations of the tuff of Toiyabe and the reasons for the abandonment of the name Toiyabe Quartz Latite. The unit consists of crystal-rich, densely welded and devitrified rhyolitic ash-flow tuff and plugged vents of a related coarser grained facies. The tuff of Toiyabe was derived from the Toiyabe volcanic center, part of which is in the southwestern part of the study area (pl. 1).

Basaltic andesite of Ledbetter Canyon intruded and locally overlies the tuff of Toiyabe in the southwestern part of the study area. This sparsely porphyritic basaltic andesite was erupted from a large, nearly circular vent at the extreme southwest corner of the study area. A mineralized quartz vein in the Ledbetter Canyon mine, west of the basaltic andesite intrusion, is spatially associated with a dike that resembles the basaltic andesite of Ledbetter Canyon.

Tertiary and (or) Quaternary rocks

Basalt lava flows of Tertiary and (or) Quaternary age unconformably overlie the basaltic andesite and the tuff of Toiyabe at the western edge of the study area. These lavas erupted from vents on or near Black Mountain.

Surficial Quaternary units include extensive basin fill in Big Smoky Valley to the east and in Reese and Indian Valleys to the west as well as local deposits of alluvium along stream courses in the study area. Several landslides are present. Glacial till and outwash deposits occur only at the highest elevations near Mahogany Mountain and Arc Dome.

Structural Geology

At least four periods of deformation and faulting are recognized within the study area. (1) Late Proterozoic and Paleozoic rocks were intensely folded and thrust faulted during Paleozoic and Mesozoic time prior to extrusion of the Darrough Felsite. (2) The Darrough Felsite was faulted against the Late Proterozoic and Paleozoic rocks along high-angle faults. The faults may be in part older than intrusion of the Cretaceous Ophir pluton, as the pluton apparently intruded along a fault between the Darrough Felsite and the Late Proterozoic and Paleozoic rocks in the North Twin River area. These faults or similar-trending faults may have been active after intrusion of the Ophir pluton because granite porphyries younger than the Ophir pluton were intruded along high-angle faults. (3) High-angle, dominantly northwest-trending faults cut the Tertiary volcanic rocks. These faults may be related to crustal extension contemporaneous with Oligocene and Miocene volcanism, as suggested by rapid pinch out of units and unconformities (Brem and others, 1985). High-angle faulting southwest of a line defined by Peavine Canyon and Reese River was also the locus of major eruptions from the Peavine and Toiyabe volcanic centers. The Toiyabe volcanic center, in the southwest corner of the study area, is marked by steep caldera-bounding faults near the Reese River and by thick intracaldera fill of tuff that overlapped much of the caldera rim except its northeast corner (pl. 1). Similar volcanic and tectonic structures related to the tuff of Arc Dome may be buried beneath alluvium in the Reese River Valley northwest of the study area. (4) High-angle Basin-and-Range faults striking north or northeast cut all rock units and some alluvial units.

Geochemical Studies

Methods

In July and August of 1983 the U.S. Geological Survey collected samples of stream sediments and prepared nonmagnetic heavy-mineral concentrates from more than 150 sites in the southern Toiyabe Range; 91 of these samples were obtained from drainages in the Arc Dome Wilderness Recommendation Area. The sampling and analytical procedures are described and the analytical data are presented in reports by Fairfield and others (1985) and Siems and others (1986). In addition, 30 rock samples were collected in 1985 to determine the geochemical features of some altered areas and mineral prospects. Geochemical results are discussed in a regional context by Nash (1988).

For this study, two media were analyzed for each sample collected from active alluvium: the minus-60-mesh (0.25-mm) fraction, and the nonmagnetic heavy-mineral fraction. The nonmagnetic fraction concentrates certain minerals that generally are related to mineralizing processes or to accompanying alteration.

All samples were analyzed for 31 elements using a six-step semiquantitative emission spectrographic method (Grimes and Marranzino, 1968). In addition, rock and stream-sediment samples were analyzed by atomic absorption spectrometry (modified from Viets, 1978) for antimony, arsenic, bismuth, cadmium, and zinc.

Results and Interpretation

Analytical results for stream-sediment and concentrate samples provide the basis for this geochemical interpretation. The framework for the interpretation includes U.S. Geological Survey geochemical studies of the surrounding Tonopah 1° by 2° quadrangle; these studies include analyses of more than 1,200 samples of stream sediments, an equal number of concentrates, and more than 2,000 samples of mineralized rocks from mines and prospects (Nash, 1988; Nash and Siems, 1988). We interpret the geochemistry of the Arc Dome Wilderness Recommendation Area by comparing it with the geochemical signatures of stream-sediment samples, known deposits, and mining areas in the regional context of the Tonopah quadrangle. In this evaluation, sites characterized by anomalous concentrations of one or more elements in both sample media, multiple-element associations that are consistent with geochemical theory, and element associations recognized in known ore deposits are considered the most reliable for mineral assessment. A few scattered single-site anomalies and four areas of multiple sites characterized by several anomalous metals have geochemical signatures that are not readily related to known types of mineral occurrences.

More than half of the stream-sediment sites in the Arc Dome Wilderness Recommendation Area are anomalous in one or more metals, generally in both stream-sediment and concentrate media. In this report, geochemical results are considered to be anomalous if they equal or exceed the 75th percentile of results from the regional study of the Tonopah quadrangle and are highly anomalous if they equal or exceed the 95th percentile.

Anomalous concentrations of metals occur at 17 sites in and northeast of the study area in drainages from Summit Creek to an unnamed canyon south of South Twin River on the east side of the Toiyabe Range. These sites are characterized by anomalous and highly anomalous concentrations of bismuth, copper, molybdenum, lead, and tungsten in concentrate samples, and silver, arsenic, copper, lead, antimony, and zinc in stream-sediment samples. Sites near Ophir Creek canyon contain relatively more bismuth, molybdenum, and tungsten than sites to the north and south that contain relatively more arsenic, copper, and zinc. The bismuth-molybdenum-tungsten anomalies may be related to tungsten skarn in rocks near the Ophir pluton. Enrichment of bismuth and tungsten have been noted in samples from skarn occurrences southwest of the study area in the Pilot and Cedar Mountains (Nash and others, 1985a, b). Silver and (or) gold are commonly associated with skarns. Other anomalous concentrations of metals are consistent with known polymetallic vein occurrences such as those at the Murphy mine and Grizzly prospect (Nos. 9, 10, pl. 1), and at other nearby prospects. Polymetallic mineral occurrences in the lower Twin Rivers drainages are associated with granite porphyry and apparently result in geochemical anomalies that are indistinguishable from those resulting from veins spatially associated with the Ophir pluton.

Nine sites in the middle and upper drainages of North Twin River and the North Fork of South Twin River are characterized by a polymetallic suite of elements that is slightly different from the polymetallic suite associated with the Ophir pluton. In the Twin Rivers area, stream-sediment and concentrate samples contain anomalous amounts of silver, arsenic, antimony, and zinc in addition to copper and lead. Enrichments in these elements occur elsewhere in the Tonopah quadrangle, such as in the Monte Cristo Range to the southwest and the Hot Creek Range to the east, where they are near polymetallic vein deposits that contain silver or gold (Nash, 1988). The only one of these sample sites that we visited in the study area was the K claims in the South Fork of South Twin River (No. 25, pl. 1). Here, pyrite and gold are present within veins in the Darrough Felsite. Other prospects in the Twin Rivers area, which are in Tertiary tuff, may contain a polymetallic suite of elements that is genetically and chemically different from those associated with Cretaceous plutons or granite porphyry.

Four sites in the drainages from Jett Canyon to Broad Creek in the southeastern part of the study area are characterized by anomalous silver, arsenic, copper, lead, antimony, and zinc in stream-sediment samples. This polymetallic suite of anomalous elements is broadly similar to that in the lower Twin Rivers drainages and, as in the Twin Rivers area, is related to polymetallic vein occurrences in sedimentary rocks adjacent to granite porphyries.

Drainages on the west slope of the range, from the Reese River north to Clear Creek, contain anomalous metal concentrations. Of 30 sites, 24 have anomalous to highly anomalous concentrations of one or more elements in the group of arsenic, molybdenum, lead, antimony, and zinc in stream-sediment samples and in the group of antimony, tin, and zinc in concentrate samples. This suite of elements is similar to that observed elsewhere in the Tonopah quadrangle in rock samples from epithermal silver-bearing base-metal vein deposits. Enrichments of the magnitude found from Reese River to Clear Creek are also observed in stream-sediment and concentrate samples from the Pilot Mountains and Paradise Range to the west, where there are known base-metal vein deposits (Nash, 1988). The origin of anomalous element concentrations in the area from Reese River to Clear Creek is not understood, as the area is underlain by the tuff of Arc Dome and the tuff of Toiyabe, neither of which appears to be altered or mineralized. The magnitude of zinc and tin enrichment in particular is unusual and cannot be explained with available data. North of the study area in the Ophir Summit and Crane Canyon areas, similar geochemical anomalies may be related to polymetallic mineral occurrences in Tertiary volcanic and underlying rocks; however, anomalous element concentrations south of Clear Creek cannot be related to known mineralization.

Geophysical Studies

Geophysical studies utilized for mineral resource assessment of the study area consisted of analysis of published aeromagnetic and Bouguer gravity maps.

Aeromagnetic Data

Magnetic features of the study area were evaluated by interpreting an aeromagnetic map (Plouff, 1990) compiled from a survey flown at a constant elevation of 12,000 ft above sea level (U.S. Geological Survey, 1971). The flight paths were closer to the ground surface over peaks than over valleys. Because surface rocks generally have normal magnetizations, magnetic highs tend to occur over hilltops and ridges, and magnetic lows tend to occur over valleys.

An elongate positive magnetic anomaly about 7 mi wide by 19 mi long extends from Pablo Canyon north to Crane Canyon and generally coincides with the crest of the range. Within this anomaly is a complex magnetic high about 5 mi in diameter between Mahogany Mountain and Toiyabe Dome on the east side of the range. This magnetic anomaly may reflect the topographic high, but it may also reflect strongly magnetized rocks in older tuffs on Mahogany Mountain and in andesite south of Toiyabe Dome. A local magnetic high about 2 mi in diameter at the north end of the larger anomaly over Ophir Summit may reflect, in part, topographic effects, but it may also reflect magnetic minerals in dioritic intrusive rocks underlying the area.

A complex magnetic high and associated magnetic lows coincide with the Toiyabe volcanic center. A horseshoe-shaped (open to the east) magnetic high, approximately 10 mi in diameter, possibly reflects magnetic minerals in the tuff of Toiyabe south and west of Arc Dome. This magnetic high is bordered to the north and northeast (between Black Mountain and Arc Dome) by a 2-mi-wide annular magnetic low that may be a normal polarization effect of the magnetic high. A 2- by 9-mi northwest-elongated magnetic low within the open end of the horseshoe-shaped high extends from upper Peavine Canyon westward beyond the Ledbetter Canyon mine (No. 32, pl. 1). This magnetic low may reflect reversely magnetized minerals in the basaltic andesite of Ledbetter Canyon, whose outcrops coincide with the magnetic low.

A 2- by 6-mi northeast-elongated magnetic low extends from the head of Trail Creek northward down Trail Creek and up the west side of the uppermost part of the Reese River. This magnetic low may reflect weakly magnetized rocks in the area. Much of the rock underlying this area is hydrothermally altered, with replacement of igneous minerals by clay minerals and quartz. Gold has been recovered from placer deposits in Trail Creek below part of the altered rock.

Gravity data

Gravity features were evaluated by interpreting 2-mGal contours on a map based on data from about 380 gravity stations. Data were taken from Healey and others (1981), Saltus and others (1981), and Bol and others (1983). The resulting gravity map shows features and numerical values of maxima and minima that are broadly similar to those on an older map (Healey and others, 1981); however, the newer map shows considerably more detail and contains more gravity data, especially near volcanic centers recognized after 1981. Gravity anomaly interpretations presented below are consistent, with allowance for new data, with interpretations of Snyder and Healey (1983).

Gravity maxima in the southern Toiyabe Range coincide with outcrops of pre-Tertiary rocks. Gravity maxima of –200 to –190 mGal coincide with Late Proterozoic and Paleozoic rocks and Mesozoic diorite. A 5-mi-diameter, slightly elongate gravity maximum north of Ophir Creek along the range crest coincides with Late Proterozoic and Paleozoic rocks and minor intrusive diorite. A northward-elongated gravity maximum coincides with Late Proterozoic and Paleozoic rock outcrops and extends from Broad Creek southward beyond the study area along the eastern part of the range. Less intense gravity maxima of approximately −210 mGal coincide with outcrops of densely silicified Darrough Felsite. A broad northward-elongated gravity maximum of approximately −210 mGal extends along the east side of the range from Ophir Creek to Broad Creek and coincides with outcrops of the Darrough Felsite.

Gravity minima of less than −210 mGal coincide with areas of thick Tertiary volcanic rocks. A 3-mi-diameter circular gravity minimum of −220 mGal coincides with a thick sequence of tuffs underlying Arc Dome. Gravity minima of −220 to −230 mGal are present south of Arc Dome and the upper Reese River, as well as within the Reese River Valley. An ovoid gravity minimum southwest of Arc Dome and 9 by 12 mi in diameter is interpreted to reflect an accumulation of as much as 11,000 ft of low-density tuff in the caldera of the Toiyabe volcanic center (Brem and others, 1985). Steep gravity gradients and lithologic relations suggest that the northern part of the caldera boundary extends from Black Mountain to beyond the Reese River and then south beyond the study area (pl. 1). An ovoid gravity minimum approximately 8 mi in minimum diameter may reflect a thick accumulation of low-density alluvial fill in the Reese River Valley; however, geologic data suggest that this gravity minimum may mark a volcanic center that erupted the tuff of Arc Dome (pl. 1). If a caldera is present, its margin would be a favorable environment for hydrothermal activity and mineralization.

Mineral and Energy Resources

Tungsten skarns

Tungsten-bearing skarns constitute a major type of mineral occurrence in and adjacent to the Arc Dome Wilderness Recommendation Area. Einaudi and others (1981) have recognized several types of skarns on the basis of characteristic mineralogical, compositional, and geochemical properties and have classified them by their predominant metals. One type is tungsten skarn, which is also called Bishop type because of its well-studied deposits near Bishop, Calif.

Skarn deposits in the southern Toiyabe Range bear the following similarities to the tungsten-skarn model of Einaudi and others (1981): (1) skarn mineralization is spatially associated with the oldest phase of the Ophir pluton, a gneissic biotite granodiorite that is cut by pegmatite and aplite dikes; (2) skarn mineralization is localized within calcareous strata of the Late Proterozoic and Paleozoic wall rocks; (3) skarn mineralization is restricted to the contact zone of the pluton with sedimentary rocks; (4) sulfide minerals include molybdenite and pyrite; however, stream-sediment and heavy-mineral-concentrate geochemical anomalies of bismuth, copper, lead, molybdenum, and zinc may, in part, be related to skarn mineralization; and (5) the richest tungsten deposits occur in late-stage quartz- and scheelite-bearing shear zones that crosscut the skarn; some tungsten may also occur in pegmatite dikes and sills.

Skarn mineralization formed near the contacts between the Ophir pluton and Late Proterozoic and Paleozoic rocks in and near the northeastern part of the study area and near the Aiken Creek pluton, about 2 mi northeast of the study area. Rocks immediately adjacent to intrusive contacts have a high mineral resource potential for tungsten, certainty level D (fig. 2; pl. 1). Although the principal tungsten production near the Ophir pluton has been outside the study area on the north wall of Ophir Creek canyon, the area along the west side of the pluton also has a high resource potential for tungsten, certainty level D, because biotite granodiorite associated with tungsten skarn minerals occurs as far south as the interfluve between Hercules Creek and North Twin River and because stream-sediment and heavy-mineral-concentrate samples from this area have geochemical anomalies characteristic of tungsten skarn mineralization. Drainages from south of Hercules Creek to the unnamed drainage south of South Twin River also have stream-sediment geochemical anomalies associated with skarn and (or) polymetallic mineralization, but no skarn mineralization was recognized and no resource potential is assigned for tungsten there. An area about 1 mi south of the southeast corner of the study area has moderate resource potential, certainty level C, for tungsten in skarn at the edge of a granite porphyry dike.

Polymetallic Veins

Polymetallic veins and disseminated minerals constitute a second major type of mineral occurrence in and adjacent to the Arc Dome Wilderness Recommendation Area. Within the study area, polymetallic vein mineralization has formed in three geologic environments: (1) veins and disseminated minerals in Late Proterozoic and Paleozoic rocks near granitic plutons; (2) veins in sedimentary and silicified volcanic rocks intruded by granite porphyry dikes and stocks; and (3) veins in and below Tertiary volcanic rocks. We discuss the mineralization according to the environments despite our inability to clearly distinguish between different mineralization events in every area.

In Late Proterozoic and Paleozoic rocks, polymetallic veins and disseminated minerals that are spatially associated with the Ophir and Ophir Summit plutons could be related to late-stage hydrothermal alteration associated with pluton emplacement and (or) skarn mineralization. Late-stage hydrothermal mineralization related to pluton emplacement has been reported at the Pine Creek mine near Bishop, Calif. (Gray and others, 1968), in other tungsten-skarn deposits (Einaudi and others, 1981), and in mineral deposits in the Toiyabe Range north of the study area (Kleinhampl and Ziony, 1984). However, younger mineralization unrelated to the pluton cannot be ruled out.

North and west of the Ophir pluton, polymetallic veins and disseminated minerals occur in an annular ring outside the skarn zone that crosses the northeast corner of the study area. Polymetallic veins along the west side of the pluton extend into the wilderness recommendation area. Although the principal metal production was outside the study area at the Murphy mine (No. 9, pl. 1) and the Murphy vein appears to die out to the south, mineralized rocks are present along the same general trend in the more gold-rich Grizzly, White Horse, and Korf properties (Nos. 10, 17, and 18, pl. 1). The mineral resource potential in the area west of the Ophir pluton is high, certainty level D, for silver, gold, lead, zinc, copper, and antimony near the Murphy mine and for gold near the other three properties to the south; it is moderate, certainty level C, for silver, gold, lead, zinc and copper in an annular ring around the adjacent Ophir pluton because of favorable rock types, mineralized rocks, reported assays, and geochemical anomalies. Polymetallic mineral occurrences just east of Ophir Summit at the Gruss mine and Dallimore-Douglas claims (Nos. 7 and 8, pl. 1) are also spatially associated with or in Late Cretaceous plutonic rocks. The principal exploration has been at the Gruss mine, and the mineralized zone at this property appears to barely extend into the study area. However, a mineralized zone in the Dallimore-Douglas claims is within the study area. Veins in this area contain high-grade ore minerals but are discontinuous along strike. Therefore, a moderate mineral resource potential, certainty level C, for silver, gold, lead, zinc, and copper in this area is based on observed mineralized rock, reported assays, and geochemical anomalies.

Polymetallic veins spatially associated with and near granite porphyry dikes and stocks may be related to late-stage hydrothermal activity related to porphyry emplacement. Cox (1986) has recognized characteristic geochemical, petrologic, and mineralogic features of polymetallic mineral deposits that define an ore deposit model. Polymetallic veins near granite porphyry in the southern Toiyabe Range have the following features resembling those of polymetallic veins in the model of Cox (1986): (1) intermediate to felsic porphyry, some having fine-grained groundmass, in dike swarms or small stocks; (2) mineralization most common in adjacent sedimentary rocks although also found in the Darrough Felsite and granite porphyry; (3) gangue minerals of quartz, calcite, and chalcedony; (4) ore minerals of gold, pyrite, sphalerite, and galena with or without chalcopyrite, bornite, tetrahedrite, or stibnite; (5) vuggy to compact vein textures and structures showing evidence of multiphase deformation, crustification, or comb structure; (6) narrow alteration envelopes in dominantly siliceous sedimentary rocks or more widespread propylitic alteration in porphyry; and (7) geochemical anomalies of silver, arsenic, bismuth, molybdenum, lead, antimony, and zinc, some of which may also be related to skarn mineralization.

In the Twin Rivers area, south of Broad Creek, and along upper Trail Creek, polymetallic mineralization is associated with granite porphyry and pre-Tertiary rocks (pl. 1). A high mineral resource potential for gold and silver, certainty level D, at the K claims (No. 25, pl. 1) is based on favorable rock types and structures, observed mineralization, comparison with the ore-deposit model, chemical analyses of mine and dump samples, and geochemical anomalies. An eastward extension of the adjacent fault and the alteration zone has a low resource potential, certainty level C, for gold and silver. Pyritized and silicified rock in a prospect at the east end of this zone (No. 26) has anomalous concentrations of silver and bismuth only. On the basis of criteria similar to those of the K claims, the mineral resource potential is moderate, certainty level C, for silver, gold, lead, zinc, and copper, with or without antimony or arsenic, near several prospects in two narrow areas along and near the Twin Rivers area and in three areas beyond the southeast corner of the study area. Broad areas surrounding these prospects have low resource potential, certainty level C, for the same commodities. These areas have generally favorable geologic environments and stream-sediment geochemical anomalies, but mineralized areas have not been recognized. Also south of the study area, the Last Chance mine (No. 39) consists of stibnite-bearing quartz-calcite veins in fault zones that cut the Diablo Formation (Lawrence, 1963; Kleinhampl and Ziony, 1984). The mineral resource potential for antimony and silver, indicated by the presence of known mineralization, is high, certainty level D, near the mine and low, certainty level C, along Wall Canyon near it. North of the study area, a faulted Mesozoic pluton along Crane Canyon has a low resource potential, certainty level C, for gold near the Hanlon mine (No. 2, pl. 1) and may be the source of placer gold downstream.

Polymetallic veins in Tertiary volcanic rocks or in the underlying pre-Tertiary rocks constitute the third class of polymetallic mineral occurrences. Most of the information on these deposits was derived from geochemical data, and a detailed ore deposit model has not been formulated. Stream-sediment samples from these rocks have a suite of anomalous elements that is similar to the suite of anomalous elements associated with polymetallic veins near granite porphyry, but it differs in anomalous intensity and in the number of elements. The suite of anomalous elements is most like the suite associated with polymetallic veins mined for silver in the Morey mining district about 60 mi to the east (John and others, 1987).

Polymetallic veins occur in or below Tertiary rocks in at least four areas. An area of bedrock exposures of the Darrough Felsite below Tertiary tuff along Trail Creek has moderate resource potential, certainty level C, as the likely source for the placer gold in Trail Creek. Around that area and west of Trail Creek, a low resource potential, certainty level C, for gold in altered Tertiary tuff and in older rocks is based on the presence of hydrothermal alteration but an absence of geochemical anomalies. The area around the Ledbetter Canyon mine (No. 32, pl. 1), just west of the southwest corner of the study area, has moderate resource potential, certainty level C, for gold in veins within the andesite of Ledbetter Canyon. In a small area west of Ophir Summit (Nos. 3–6), the low resource potential, certainty level C, for gold, silver, and copper in polymetallic veins in Tertiary rocks is based on the presence of altered rocks and geochemical anomalies. In an area having polymetallic veins in the middle to upper drainages of North Twin River and the North Fork of South Twin River (Nos. 19, 20, and 22, pl. 1), the low resource potential, certainty level C for gold and silver and certainty level B for lead, zinc, and copper, is based on weak geochemical anomalies.

Polymetallic mineral occurrences in Tertiary rocks may also be present in the broad area extending from Reese River to Clear Creek on the west side of the study area. The area is defined by anomalous element concentrations that have been related to base-metal veins mined for silver. A low resource potential, certainty level B, for silver, lead, zinc, and antimony in the area is based on the presence of geochemical anomalies but an absence of mineralized rocks. More work needs to be done in this area to determine the origin of the geochemical anomalies.

Placer Gold and Silver Deposits

Placer gold and silver deposits in alluvium derived from exposures of gold- and silver-bearing bedrock are well known in Nevada. Local placer deposits such as those at Round Mountain and Manhattan in the Toquima Range have yielded substantial quantities of precious metals (summarized in Kleinhampl and Ziony, 1984). Prospects for placer gold in Crane Canyon (No. 1, pl. 1) and for placer gold and silver at the mouth of Ophir Creek (No. 16) are outside the study area. The area around the mouth of Ophir Creek canyon has low resource potential, certainty level C, for placer gold and silver; the sources of gold and silver might be upstream in bedrock within or near the study area. The moderate resource potential, certainty level C, for placer gold in alluvium in Trail Creek and below its junction with the Reese River (No. 29, pl. 1) is based on favorable geologic environment and on gold discoveries. The placer deposits near Trail Creek may be small, however, because the alluvium is relatively thin and restricted to narrow valley bottoms.

Energy Resources

In areas of the Basin and Range province where Quaternary igneous activity is lacking, geothermal waters have been related to meteoric water circulation along permeable Basin-and-Range faults, to conductive heating by rocks at elevated temperatures because of high regional geothermal gradients, and to convective circulation of heated waters (Brook and others, 1979; Hose and Taylor, 1974). The Darrough Hot Springs KGRA has been related to such a model (Garside and Schilling, 1979). Darrough Hot Springs has a high resource potential, certainty level D, for geothermal energy; however, the principal geothermal resources lie 1 mi east of the study area, presumably along and east of a steeply dipping, north-trending fault within the basin fill of Big Smoky Valley (No. 40, pl. 1). Fault scarps in Quaternary alluvium along the east side of the Reese River Valley adjacent to the northwest margin of the study area, as well as gravity data that indicate a thick layer of rather low-density fill in the valley, suggest a favorable environment for geothermal resources there. Geothermal energy resources, if present, would most likely occur west of fault scarps in the Reese River Valley northwest of the study area. Because the study area is a mountainous area between those two valleys, it has no geothermal energy resources, certainty level D.

Oil and gas have been discovered in eastern Nevada; however, none has been reported near the study area. Sandberg (1983) evaluated the petroleum resource potential as "zero" in the part of Nevada that includes the study area, primarily due to the absence of source rocks and to thermal overmaturation of any potential source rocks by Mesozoic and Cenozoic magmatism. Organic geochemical data from shales and alteration colors of conodonts from limestone and dolostone in the study area further confirm a relatively high thermal history of pre-Tertiary rocks and the thermal overmaturation of potential source rocks (F.G. Poole, unpub. data, 1985). Therefore, the study area has no energy resource potential, certainty level D, for oil and gas.

Industrial Minerals

Barite occurs in Devonian rocks north of the study area along Summit Creek canyon and southeast of it in the Toquima Range (Shawe and others, 1967, 1969; Poole and Sandberg, 1975; Kleinhampl and Ziony, 1984). However, rocks containing bedded barite have not been recognized in the study area. Limestone has been quarried at a site north of the study area (No. 15, pl. 1). Limestone and dolostone in the form of small lenses or beds occur only locally in highly deformed, dominantly clastic Late Proterozoic and Paleozoic rocks. Dimension stone, primarily in talus, also occurs locally in these rocks. Limestone, dolostone, and dimension stone resources are relatively small and are located far from potential sites of utilization; thus, we do not assign them any resource potential.

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APPENDIXES

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

LEVELS OF RESOURCE POTENTIAL

H **HIGH** mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data support mineral-deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

M **MODERATE** mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate reasonable likelihood for resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

L **LOW** mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics define a geologic environment in which the existence of resources is permissive. This broad category embraces areas with dispersed but insignificantly mineralized rock, as well as areas with little or no indication of having been mineralized.

N **NO** mineral resource potential is a category reserved for a specific type of resource in a well-defined area.

U **UNKNOWN** mineral resource potential is assigned to areas where information is inadequate to assign a low, moderate, or high level of resource potential.

LEVELS OF CERTAINTY

A Available information is not adequate for determination of the level of mineral resource potential.

B Available information only suggests the level of mineral resource potential.

C Available information gives a good indication of the level of mineral resource potential.

D Available information clearly defines the level of mineral resource potential.

LEVEL OF RESOURCE POTENTIAL →

A	B	C	D
U/A	H/B HIGH POTENTIAL	H/C HIGH POTENTIAL	H/D HIGH POTENTIAL
UNKNOWN POTENTIAL	M/B MODERATE POTENTIAL	M/C MODERATE POTENTIAL	M/D MODERATE POTENTIAL
	L/B LOW POTENTIAL	L/C LOW POTENTIAL	L/D LOW POTENTIAL
			N/D NO POTENTIAL

LEVEL OF CERTAINTY →

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GEOLOGIC TIME CHART

Terms and boundary ages used by the U.S. Geological Survey in this report

EON	ERA	PERIOD		EPOCH	AGE ESTIMATES OF BOUNDARIES IN MILLION YEARS (Ma)
Phanerozoic	Cenozoic	Quaternary		Holocene	0.010
				Pleistocene	1.7
		Tertiary	Neogene Subperiod	Pliocene	5
				Miocene	24
			Paleogene Subperiod	Oligocene	38
				Eocene	55
				Paleocene	66
	Mesozoic	Cretaceous		Late	96
				Early	138
		Jurassic		Late Middle Early	205
		Triassic		Late Middle Early	~240
	Paleozoic	Permian		Late Early	290
		Carboniferous Periods	Pennsylvanian	Late Middle Early	~330
			Mississippian	Late Early	360
		Devonian		Late Middle Early	410
		Silurian		Late Middle Early	435
		Ordovician		Late Middle Early	500
		Cambrian		Late Middle Early	[1]~570
Proterozoic	Late Proterozoic				900
	Middle Proterozoic				1600
	Early Proterozoic				2500
Archean	Late Archean				3000
	Middle Archean				3400
	Early Archean				(3800?)
pre-Archean[2]					4550

[1]Rocks older than 570 Ma also called Precambrian, a time term without specific rank.
[2]Informal time term without specific rank.