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GEOLOGIC INSIGHTS AND SUGGESTIONS ON MINERAL POTENTIAL BASED ON ANALYSES OF GEOPHYSICAL DATA OF THE SOUTHERN TOQUIMA RANGE, NYE COUNTY, NEVADA

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ABSTRACT

Aeromagnetic and gravity data provide confirmation of major structural and lithologic units in the southern Toquima Range, Nevada. These units include Cretaceous granite plutons and Tertiary calderas. In addition, the geophysical maps pinpoint numerous faults and lesser intrusions, and they suggest locations of several inferred subsurface intrusions. They also corroborate a system of northwesterly and northeasterly conjugate structures that probably are fundamental to the structural framework of the Toquima Range.

A combination of geophysical, geochemical, and geologic data available for the widely mineralized and productive area suggests additional mineral resource potential, especially in and (or) adjacent to the Round Mountain, Jefferson, Manhattan, and Belmont mining districts. Also, evidence for mineral potential exists for areas near the Flower mercury mine south of Mount Jefferson caldera, and in the Bald Mountain Canyon belt of gold-quartz veins in the Manhattan caldera. A few other areas also show potential for mineral resources.

The various geologic environments indicated within the map area suggest base- and precious-metal potential in porphyry deposits as well as in quartz-vein and skarn deposits associated with intrusive stocks.

INTRODUCTION

A comparison of magnetic and gravity maps of the area to the geology of the southern Toquima Range, Nev., is made here for the purpose of inferring subsurface structural and lithologic characteristics of the rocks as they may pertain to localization of mineral deposits. The study is not intended to be a comprehensive application of geophysical principles and methods in order to interpret specific parameters of subsurface rocks. The overall objective is to infer the geologic-structural setting of the area, and to suggest environments favorable for occurrence of mineral deposits, in order to make qualitative estimates of the mineral potential of the area. Readers are referred to a geologic map of the area at 1:48,000 scale (Shawe, 2002) to facilitate interpretation of the 1:48,000-scale magnetic and gravity maps presented here. Reference is also made to a map of steep structures (Shawe, 2001) and to several geochemical maps (Shawe, 2003) for information pertinent to the interpretations based on geophysical data for the study area. Discussion of the geology of the southern Toquima Range area given here provides a background for relating the geophysical properties of specific rock types and structures.

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GEOLOGIC BACKGROUND

A great variety of lower Paleozoic, Cretaceous, and Tertiary rocks is exposed in the southern Toquima Range (fig. 1). Based on the position of the $^{87}Sr/^{86}Sr$ 0.706 line that lies west of the area (for example, Kistler, 1991) or trends through the area (Tosdal and others, 2000), and on lead isotope data for the region (Zartman, 1974), these rocks probably are underlain by or are close to the margin of Precambrian basement.

PALEOZOIC ROCKS

Paleozoic rocks in the area are of Cambrian and Ordovician age and consist of marine argillite, limestone, siltstone, and quartzite, and metamorphic equivalents. At the resolution of the aeromagnetic survey presented here, they can be considered effectively nonmagnetic. Specific gravity measurements (Shawe and Snyder, 1988) of Paleozoic rocks are estimated from two surface samples of (probably) silty limestone that gave values of 2.65 g/cm^3 and 2.68 g/cm^3 (average about 2.67 g/cm^3). In general, limestones can have densities as high as about 2.8 g/cm^3, argillites probably are about 2.67 g/cm^3, and siltstones and quartzites are less dense (see for example Telford and others, 1990). The exposed Paleozoic rocks consist of considerably more than one-half siliceous-detrital strata, the balance being denser carbonate (mostly limestone) rocks. Lower thrust plates of the Paleozoic rocks are predominantly siliceous-detrital strata, which constitute the bulk of the volume of all Paleozoic rocks, suggesting that the entire Paleozoic package underlying the area is less than one-quarter carbonate rocks. This mixture of rock types indicates that the overall density of the Paleozoic section is probably close to 2.67 g/cm^3.

A thrust plate of Paleozoic oceanic rocks exposed in the south-central part of the map area consists chiefly of greenstone, chert, and graywacke; a small part of the plate is magnetite-bearing serpentinite (expected to be very magnetic). Average density of this thrust plate of varied lithologies is probably no more than about 2.6 g/cm^3.

The Paleozoic rocks have been extremely deformed by folding and thrust faulting; whether or not the lowest thrust plate identified at the surface is underlain by other plates is unknown. In general the Paleozoic rocks form the structural "underpinnings" of the area.

CRETACEOUS GRANITE PLUTONS

Cretaceous granite plutons emplaced in Paleozoic rocks in the map area are the Round Mountain pluton (90 Ma), Belmont pluton (85 Ma), and north part of Pipe Spring pluton (80 Ma) (locations shown on Maps A and B). Round Mountain and Belmont plutons consist of coarse-grained granite that was invaded by aplite and fine-grained granite, domed, metamorphosed, and mineralized at about 80 Ma. The Belmont pluton is a differentiated and stratified intrusion characterized by an upper zone of porphyritic granite, an intermediate zone of sparsely porphyritic granite, and a lower zone of coarse-grained granite. In its present eroded form, as a result of doming, the porphyritic zone is present only in the outer part of the body and nonporhyritic granite is exposed in the core of the pluton. Pipe Spring pluton was invaded by aplite and fine-grained granite, domed, metamorphosed, and mineralized at about 75 Ma. The plutons probably were emplaced as thick sills and subsequently domed; geophysical evidence for their sill-like (or laccolithic?) nature is discussed in a following section. All are two-mica granites that gained their character as a result of post-emplacement metamorphism. Specific gravities of three surface samples of granite are 2.60 g/cm^3, 2.61 g/cm^3, and 2.62 g/cm^3, indicating an average density of about 2.61 g/cm^3 (Shawe and Snyder, 1988). They contain minor amounts of iron-titanium oxides (in part magnetite), but their magnetic properties have not been determined. Small dikes of 75-Ma granodiorite were emplaced into Paleozoic rocks just east of the Pipe Spring granite pluton. Paleozoic rocks near granite (within a few meters to a few hundred meters) are contact metamorphosed such that argillic rocks were converted to schists, and carbonate rocks were converted to marble or calc-silicate-mineralized rocks, some of which contain magnetite.

TERTIARY INTRUSIVE AND VOLCANIC ROCKS

Intrusive rocks that are about 36 Ma consist of a granodiorite stock emplaced in granite of the Round Mountain pluton and wallrocks (Maps A and B), and a swarm of northeast-striking rhyolite and andesite dikes emplaced in granite about 5 km east of Round Mountain (not shown on Maps A and B; see Shawe, 1995, for location). The stock is significant in respect to interpretation of mineralization history of the area because it is surrounded by a halo of mineralized ground (Shawe, 1988; Shawe, 2003). Neither magnetic property nor density data were acquired on the intrusive rocks.

Volcanic rocks in the map area consist of ash-flow tuffs and related intrusive rocks associated with the Mount Jefferson caldera (Maps A and B; Shawe, 1995; 1999b; Shawe and others, 2000), ash-flow tuffs and related intrusive rocks associated with the Manhattan caldera (Maps A and B; Shawe, 1998; 1999a), ash-flow tuffs associated with calderas buried beneath alluvium of Big Smoky Valley (Maps A and B; Henry, 1997; Henry and others, 1996), and volcanics in the southeast part of the map area that may be related to two calderas, an inferred one underlying Monitor Valley (Maps A and B; Shawe and Byers, 1999), and the Big Ten Peak caldera (Keith, 1987, 1993) south of the map area. Ages of dated volcanic rocks range from about 27.2 Ma to about 22.8 Ma; an isolated patch of vitric ash tuff is dated at about 12 Ma. Average measured specific gravity of surface samples of volcanic rocks in the Manhattan caldera is about 2.32 g/cm^3 (Shawe and Snyder, 1988). Ash-flow tuffs (12 samples) within the caldera range in density from 1.94 g/cm^3

(poorly consolidated tuffs) to 2.37 g/cm^3 (densely welded ash-flow tuffs). A surface sample of dacite (dacite of Ferguson Hill) has a density of 2.40 g/cm^3 and a surface sample of andesite (Crone Gulch Andesite) has a density of 2.64 g/cm^3 (locations of both volcanic units shown by Shawe, 1999a). Average densities of similar volcanic rocks elsewhere in the region, such as at the southern Nevada volcanic field (Healey, 1970; Grauch and others, 1999; Hildenbrand and others, 1999), are similar. Magnetic properties of the volcanic rocks were not measured in this study. However, some of the tuffs in the Mount Jefferson caldera are strongly magnetic, as they deflect a Brunton compass needle. Some, such as the tuff of Corcoran Canyon (27.2 Ma), possess reversed polarity remanent magnetism (C.S. Grommé, written commun., 2002), also suggested by a magnetic reversal from reversed to normal polarity that took place at about 26.8 Ma (Opdyke and Channell, 1996; Wei, 1995). Based on the documented reversal at 26.8 Ma, the lower parts of the tuff of Mount Jefferson and the tuff of Ryecroft Canyon, both of which were emplaced across this date, may have reversed polarity. A number of ash-flow tuff units from uncertain sources outside the map area are present in the southern Toquima Range. These rocks range in age from about 24 Ma to 12 Ma, and because magnetic reversals took place in this time interval (Opdyke and Channell, 1996; Wei, 1995) some units may have reversed polarity. For example, Sargent and McKee (1969) described rocks equivalent to unit C of the Bates Mountain Tuff (about 23.7 Ma) as having reversed polarity, as determined by G.D. Bath, J.D. Kibler, and Sherman Grommé of the U.S. Geological Survey.

QUATERNARY ALLUVIUM

Alluvium has significant thickness only in Monitor Valley, Big Smoky Valley, and the south part of Ralston Valley within the Belmont West quadrangle. Density of the alluvium has not been measured in our study area; it may approach 2.0 g/cm^3 in the deeper parts of valley fill, based on density data for alluvium in other valleys in the Basin-range province (Healey, 1970; Grauch and others, 1999; Hildenbrand and others, 1999). From samples collected in southwestern Nevada, Synder and Carr (1984) measured densities of alluvium ranging from 1.6 to 2.0 g/cm^3. Alluvium is generally assumed to be nonmagnetic to weakly magnetic, except where it is derived directly from magnetic rocks.

MAGNETIC AND GRAVITY DATA

The magnetic map (Map A) was generated from a digital data set collected by Aerial Surveys for the U.S. Geological Survey in October, 1978. The survey was flown at a line spacing of 800 m in an east-west direction at a nominal flight altitude of 305 m above ground. After projecting the data to transverse mercator with a central meridian of 116°40', the total-field data were gridded at a 200-m spacing using a computer program (Webring, 1982) based on minimum curvature (Briggs, 1974). A definitive International Geomagnetic Reference Field appropriate for the survey data was removed from the grid using a program by Sweeney (1990) to produce a magnetic anomaly or residual total-intensity magnetic grid. Some residual flight-line noise may be evident due to incomplete processing of the data by the original contractor. Rock magnetizations in southern Nevada can be highly varied, particularly in volcanic rocks (see Bath, 1968; Grauch and others, 1999). The total magnetization is the vector sum of two components: induced magnetization (which is proportional in magnitude and generally parallel to the Earth's ambient field) and remanent magnetization (which has a direction and intensity dependent on the origin and geologic history of the rock). Assuming induced magnetization and remanent magnetization to be aligned or nearly aligned with the Earth's magnetic field, the magnetic data were reduced to the magnetic pole, a procedure that generally shifts the anomalies to positions above their sources and results in reduced-to-pole magnetic data (see Telford and others, 1990). The assumption that remanent magnetization is collinear with induced magnetization may be valid here because the orientations of remanent magnetization in Tertiary rocks tend to lie within 25° of present-day Earth's magnetic field direction (Bath, 1968). Expression of near-surface sources can be enhanced using shaded relief maps (figs. 2 and 3). Shaded relief analysis applies a derivative filter to sharpen or decrease the effects of near-surface sources trending, respectively, normal or parallel to the direction of illumination. The unfiltered (Map A) and shaded relief (figs. 2 and 3) reduced-to-pole magnetic data illustrate the effectiveness of this approach to highlight subtle geologic information normal to the direction of illumination.

The gravity map (Map B) was generated from data distributed by the National Geophysical Data Center (Hittleman and others, 1994). The observed gravity data relative to the IGSN-71 datum (Morelli, 1974) of 365 stations were reduced to the Bouguer anomaly using the 1967 gravity formula (International Association of Geodesy, 1967) and a reduction density of 2.67 g/cm^3. Standard USGS gravity reduction equations and related formulae are discussed in Cordell and others (1982). Terrain corrections were made for the area extending radially from each station at a distance of 0–167 km using the computer method of Plouff (1977) and digital terrain. After projecting the data to transverse mercator with a central meridian of 116°40', the Bouguer gravity anomaly values were gridded at a 500-m spacing using a computer program (Webring, 1982) based on minimum curvature (Briggs, 1974). The gravity effects of an Airy-Heiskanen model (Simpson and others, 1986) with a density contrast of 0.4 g/cm^3 between crust and mantle, a topographic load density of 2.67 g/cm^3, and a depth of 30 km to Moho were then subtracted from the Bouguer anomaly grid to produce the isostatic residual gravity anomaly grid. Removal of this regional effect helps isolate gravity anomalies arising from sources in the upper crust from those that are deeper (Simpson and others, 1986).

A synthesis of the gravity effects of basement (rocks underlying Quaternary sediments and Tertiary volcanic rocks) and basin thickness (depth to Cretaceous granite plutons, Paleozoic marine sedimentary rocks, and possibly underlying Precambrian metasedimentary and metaigneous rocks) in a wide region of the Western United States (Saltus and Jachens, 1995) provides new insights on the gross structural and lithologic configuration of basement rocks in the southern Toquima Range. Using a gravity inversion method, Jachens and Moring (1990) divided the isostatic gravity anomaly into a basin field and a basement field of Nevada. From their results, the basement gravity field in our study area (fig. 4) generally reflects changes in density related to lithologic variations within the dense pre-Tertiary rocks. Jachens and Moring (1990) used the complementary basin gravity field to calculate variations in the thickness of low-density Cenozoic volcanic and sedimentary rocks (for example, fig. 5). In the inversion process, the density of basement is allowed to vary horizontally but the density of basin-filling deposits is fixed using a representative density versus depth relationship. The accuracy of the thickness results is highly dependent on the assumed density-depth relation of the Cenozoic rocks (generally layers with densities $<2.5 g/cm^3$) and the initial density assigned to basement rocks ($2.67 g/cm^3$). Jachens and Moring (1990) used the following density-depth relationship in compiling a Nevada Cenozoic basin thickness map: 0–200 m—$1.9 g/cm^3$, 200–600 m—$2.1 g/cm^3$, 600–1,200 m—$2.3 g/cm^3$, and >1,200 m—$2.45 g/cm^3$. Complicating this task of selecting these representative densities at a particular depth for Nevada by Jachens and Moring (1990) is the significant variation in density related to the degree of welding and alteration of the ash-flow tuffs, to structure (for example, landslides and shallow, dense intrusions), and to water saturation. For example in our study area, if Tertiary volcanic rocks are dense (such as the tuff of Corcoran Canyon, $2.4 g/cm^3$, discussed later), or if dense Tertiary intrusions are present, the thickness of Cenozoic rocks in figure 5 will be locally underestimated.

In the following text, the regional variation in density and magnetic rock properties within the map area will be discussed utilizing the various geophysical maps cited above (Maps A and B, figs. 2–5). In places, identification of geographic locations will be made by reference to position within respective 1:24,000-scale quadrangles that are shown on the index map.

Discussion of the geology of the southern Toquima Range area given herewith provides a background for relating the geophysical properties to specific rock types and structures. The discussion is based on numerous earlier publications by Shawe and coworkers (see References Cited).

COMPARISON OF GEOLOGIC AND GEOPHYSICAL DATA

GROSS RELATIONS BASED ON BASEMENT GRAVITY AND BASIN THICKNESS

The basement gravity map (fig. 4; Saltus and Jachens, 1995), estimating the effects of removing overlying Quaternary sediments and Tertiary volcanic rocks, reflects very broadly the density of basement rocks, generally the Paleozoic marine sedimentary rocks and metamorphosed equivalents, and Cretaceous granite plutons. Areas of relatively low density coincide roughly with granite plutons (estimated densities generally $0.06 g/cm^3$ less than those of Paleozoic rocks) exposed in the east part of the Round Mountain quadrangle, south part of the Jefferson quadrangle, and north part of the Belmont West quadrangle. A broad zone of inferred less dense basement rocks is apparent in much of the Belmont East quadrangle where granite is not present at the surface except at the west edge of the quadrangle. Areas surrounding the basement low-density zone in the southern Toquima Range are interpreted as characterized by higher density Paleozoic (perhaps also higher density buried Precambrian) sedimentary and metasedimentary (also metaigneous?) rocks. Higher density basement rocks (representative densities of $2.67 g/cm^3$ or more) are particularly evident in the west parts of the Round Mountain and Manhattan quadrangles.

On the map showing thickness of Quaternary sediments and Tertiary volcanic rocks (fig. 5), areas of less than 75 m thickness generally coincide with exposures of Paleozoic rocks (especially the south part of the Manhattan quadrangle) and Cretaceous granite plutons. In the upper (north) end of Ralston Valley, in the south-central part of the study area, indication of less than 75 m of basin fill corroborates the interpretation (Shawe, 1998) that the granite has a pedimented surface below thin alluvium, and that this part of the valley is not depressed as a graben. A thin layer of alluvium also may occur along the east structural margin of the Mount Jefferson caldera. The associated gravity high may reflect a relatively thick volcanic layer in the Corcoran Canyon quadrangle (Shawe and others, 2000). The interpreted thick tuff of Corcoran Canyon possibly represents dense ($2.4 g/cm^3$) intracaldera fill of a caldera (27.2 Ma) older than the nested Mount Jefferson caldera (26.8 Ma; Shawe and others, 2000). As discussed in a later section, significant magnetic lows in this area probably reflect the reversed magnetic polarity of the tuff of Corcoran Canyon. The gravity map (fig. 5) thus suggests that the interpretation of thick tuff of Corcoran Canyon of unusually high density (Shawe and others, 2000) may apply only to a zone immediately adjacent to the margin of the Mount Jefferson caldera and thus more limited in area than earlier thought.

Depth to basement of as much as 2 km in an oval-shaped area within the Mount Jefferson caldera suggests a thick volcanic section consistent with intracaldera tuff, but considerably smaller in area than the caldera itself. The area of increased thickness may represent the source of the tuff of Corcoran Canyon (27.2 Ma), which is older than the tuff of Mount Jefferson (26.8 Ma), or alternatively the limited area can be explained by variations in density of the intracaldera tuff of Mount Jefferson not accommodated in the inversion, such as variations in degree of welding of the tuff (Healey, 1968; Carroll, 1989; Ferguson and others, 1994).

The Big Ten Peak caldera (Keith, 1987) may extend northward into the south part of the Belmont East quadrangle. Some of the volcanic rocks in the south part of the Belmont East quadrangle are inferred to be related to the Big Ten Peak caldera (Shawe and Byers, 1999). In the southeast part of the quadrangle, indication of depth to basement of as much as 3 km where volcanic rocks crop out strongly suggests another caldera that lies mostly south of the quadrangle.

Depth to basement of as much as about 1 km in an oval-shaped area in the north part of the Manhattan quadrangle clearly relates to the Manhattan caldera. This depth agrees with that derived from a gravity model (Shawe and Snyder, 1988), which gave thickness of low-density caldera fill as 700–1,400 m.

In the northeast part of the Belmont East quadrangle and east part of the Corcoran Canyon quadrangle, basin thickness ranges from about 1 km to about 7 km, thinning dramatically from north to south. Much of the basin fill must be Quaternary alluvium in Monitor Valley, but part may be tuff of Ryecroft Canyon interpreted to fill a proposed caldera underlying the south part of Monitor Valley that was the presumed source of the tuff (Shawe and Byers, 1999). The positive magnetic anomaly over Monitor Valley just southeast of the Mount Jefferson caldera may indicate the presence of a block of normal-polarity upper unit of the tuff of Ryecroft Canyon. As in Monitor Valley, in the northwest part of the Round Mountain quadrangle, thick basin fill likely consists of both low-density Quaternary alluvium and Tertiary ash-flow tuff filling calderas inferred by Henry and others (1996).

EVALUATION OF EXPOSED AREAS OF PALEOZOIC ROCKS

Magnetic response over exposed Paleozoic rocks in general ranges from about −100 to 100 nanoTeslas (nT). In the Manhattan area a string of magnetic highs, lying mostly south of and roughly paralleling the northwest-striking Manhattan fault, is probably related to buried intrusions. The magnetic highs are especially well shown on figure 2, reduced-to-pole magnetic map data “illuminated” from the northeast. Because the proposed intrusions are subparallel to the fault, the fault may have controlled emplacement of intrusions. Southeast of a neck of the Pipe Spring granite pluton that interrupts the Manhattan fault, a magnetic high (40 to 60 nT) may reflect a 75-Ma granodiorite dike that crops out in that area. Altogether, the data suggest that a structurally controlled northwest-trending line of intermediate composition intrusions accounts for the northwest-trending magnetic boundaries.

Over Paleozoic rocks in the central and east part of the map area, gravity values generally range from −34 to −20 mGal (Map B). In the west part of the map area, however, values are higher and generally range from about −28 to −6 mGal. The rocks exposed in both areas are the same formations, suggesting that the lithologies and (or) depths of subsurface rocks in the two areas are different. As the basement-gravity map (fig. 4) indicates, rocks underlying alluvium and volcanic rocks to the west may have higher densities than those of basement beneath alluvium and volcanic rocks to the east. Rocks of higher density than the Paleozoic rocks (about 2.67 g/cm^3, mean of the specific gravity of Paleozoic rocks, Shawe and Snyder, 1988) may exist in the subsurface in the western area; among possibilities are mafic igneous rocks, for example, gabbro—specific gravity about 3.0 g/cm^3—or other rocks of a Paleozoic oceanic assemblage, or intermediate intrusions of Late Cretaceous or Tertiary age, as discussed in the previous paragraph.

Southeast of the Belmont granite pluton, a local magnetic high (80 nT amplitude) appears to be caused by magnetite-bearing serpentinite. A broad gravity high (−22 to −20 mGal) mostly south of the serpentinite suggests an area of higher density rocks underlying alluvium and volcanic rocks, but probably not serpentinite (which is here thoroughly serpentinized and thus of density probably less than 2.6 g/cm^3).

A gravity high (−20 to −16 mGal) is centered over Paleozoic rocks in the south part of the Round Mountain quadrangle. The Paleozoic rocks in the area consist of intermixed carbonate (density probably about 2.7 g/cm^3, based on densities reported in the literature, for example Telford and others, 1990), and less dense argillite and quartzite (density about 2.6 g/cm^3), contrasting with the very low density volcanic rocks and alluvium (densities less than 2.4 g/cm^3). The Paleozoic rocks thus may account for the gravity high. Conversely, the high may reflect a buried intrusion such as andesite (density roughly 2.7 g/cm^3). Such a buried intrusion seems likely, inasmuch as there are anomalous concentrations of metals in mineralized rocks in this area (see Shawe, 2003, for details of mineralized rocks).

An east-trending magnetic high (−20 to 0 nT) over Paleozoic rocks south of the Flower mercury mine in the Jefferson quadrangle is an eastward extension of a magnetic ridge whose west end is a more intense magnetic high (40 to 60 nT) near the juncture of the Belmont pluton and Round Mountain pluton with Paleozoic rocks farther west (Map A). Even farther west is a gravity high (−16 to −18 mGal; Map B, discussed in the previous paragraph) that may reflect an underlying intrusion possibly related to mineralized rocks at the surface (see Shawe, 2003, for details of mineralized rocks). Along the east part of the magnetic high zone and just north of it, a −22 to −20 mGal gravity high lies just west of the Flower mercury mine. This subtle gravity anomaly unfortunately is based on only one gravity station. However, evidence of mineralization in the vicinity of the mine suggests proximity of a buried intrusion. Superimposed on the magnetic and gravity maps (Maps A and B), in the vicinity of the Flower mine, is an outline showing distribution of anomalous values of boron in geochemical rock samples (Shawe, 2003). The boron is interpreted to indicate a tourmaline-mineralized zone related to the postulated buried stock (reflected by the −22 to −20 mGal gravity anomaly) around which there may be base-metal and (or) precious-metal deposits.

The gravity and magnetic highs together may represent an east-west alignment of intrusions that coincides with a zone of mineral deposits. The linear magnetic zone extends remarkably from mineralized Paleozoic rocks south of Round Mountain gold mine eastward along a trend of mercury mines (Red Bird Toquima, Van Ness) and prospects (including Mariposa Red Dog), the Barcelona silver mine, and to the Flower mercury mine just north of the magnetic ridge (Maps A and B; see also, Shawe, 2003). Major east-trending structural zones in this region of the Basin-range province have been noted by Stewart (1988) and by Ekren and others (1976).

EVALUATION OF EXPOSED AREAS OF CRETACEOUS GRANITIC ROCKS

Magnetic response of the Round Mountain pluton ranges mostly between −20 and 20 nT. A −20 to 0 nT magnetic high is centered on a large intrusion of fine-grained granite that invaded the core of the pluton and was likely responsible for doming the pluton. Arcuate reverse faults that are concentric with the fine-grained granite and the magnetic high probably broke as a result of the intrusion of the fine-grained granite (Shawe, 1999b). A zone of lower magnetic response, roughly −20 to −60 nT, surrounds the central fine-grained granite core. One possible explanation for the correspondence of the magnetic high related to the central core is that the pluton is concentrically zoned, the zones having varied magnetic properties. Rock magnetic properties would greatly improve our understanding of the varied magnetic character of the pluton. However, if it is assumed that granite and aplite have comparable magnetite contents, a possible explanation of lower magnetic response peripheral to the fine-grained core of the pluton could be a laccolith-shaped intrusion whose deeply rooted central stem accounts for the higher magnetic response. Also, if the granite were nonmagnetic, a mafic or intermediate-composition core underlying the dome could produce the observed magnetic pattern.

A 100 to 150 nT anomaly is centered over a 36-Ma granodiorite stock (granodiorite of Dry Canyon) emplaced in the northwest part of the Round Mountain pluton, which is surrounded by a halo of mineralized ground (Shawe, 1988). The granodiorite contains 0.5–1.5 percent opaque oxide minerals (Shawe, 1995; probably mostly magnetite), considerably more than the enclosing granitic rocks. The lateral extent of the granodiorite based on the magnetic data appears to be greater than the mapped outcrop, suggesting that the stock expands with depth. The source of a −100 nT northwest-trending magnetic low southeast of the Jefferson mining district may reflect reversely magnetized intrusive rocks related to the margin of an inferred caldera from which the tuff of Corcoran Canyon erupted. However, this low magnetic response zone also coincides with the position of a megabreccia dike and interpreted necks from which the megabreccia of Jefferson Summit erupted through granite not long after emplacement of the tuff of Mount Jefferson (Shawe, 1999b); it also may reflect a zone of hydrothermal alteration that surrounds the megabreccia intrusions. Hydrothermal conversion of magnetite (if normally magnetized) to pyrite in the granite may have contributed to the lower magnetic response. In any case, the Round Mountain pluton is probably thin in the zone, because the megabreccia dike and necks in the granite have brought up andesite and metamorphosed Paleozoic rocks from probably shallow depth. The granite pluton may be sill-like (or laccolithic?) in its periphery.

The moderate density (2.61 g/cm^3, Shawe and Snyder, 1988) of granitic rocks in the Round Mountain pluton is reflected by gravity values generally in the range of −26 to −20 mGal. The basement gravity map (fig. 4) clearly shows lower density rocks in places in the southern Toquima Range. The west part of the Round Mountain pluton is characterized, however, by a local anomaly (gravity high, 6 mGal amplitude), clearly reflecting a subsurface body more dense than granite. An andesite (granodiorite, diorite, or gabbro?) stock may be present, as suggested in figure 6. The gravity anomaly is an eastward extension of east-trending magnetic highs south of Round Mountain, described later, that may represent buried intrusions that caused mineralization at Round Mountain.

The Belmont pluton's general magnetic signature is similar to that of the Round Mountain pluton, namely a magnetic high (20 to 40 nT) over the core, surrounded by a zone of lower magnetic values. By analogy with the Round Mountain pluton, the magnetic pattern of the Belmont pluton may reflect a laccolithic form, or a concentrically zoned pluton. In the case of the Belmont pluton, however, the apparent concentric zonation of the pluton is a result of doming of a layered (probably sill-like or laccolithic) body.

One possibility to explain a prominent magnetic low (60 nT amplitude) in the southeast part of the Belmont pluton is the presence of a shallow detachment fault that has moved the upper part of the pluton southeastward and emplaced it above Tertiary volcanic rocks of reversed polarity (age about 27.0 Ma?). A low-angle fault has displaced Paleozoic oceanic rocks southeastward about 4 km onto Tertiary volcanic rocks about 9 km south-southeast of the Belmont pluton (Shawe and Byers, 1999). It thus seems possible that granite was displaced several kilometers southeastward onto reversely polarized volcanic rocks. A second possibility is that the southeast part of the pluton was emplaced as a sill, and it is underlain at relatively shallow depth by reversely polarized rocks, either older or younger than the granite.

EVALUATION OF EXPOSED AREAS OF TERTIARY VOLCANIC ROCKS

A large gravity low (–38 to –42 mGal) in the northeast part of the Jefferson quadrangle indicates a locally thicker zone of ash-flow tuffs inside the margin of the Mount Jefferson caldera, as also interpreted from the depth-to-basement map (fig. 5). As previously stated, this zone may represent roots of a caldera older than the Mount Jefferson and related to the tuff of Corcoran Canyon, although it may instead represent caldera collapse and fill in early development of the Mount Jefferson caldera.

The Mount Jefferson caldera is marked by pronounced high and low magnetic anomalies, possibly in part related to rocks of normal polarity (most of the tuff of Mount Jefferson except perhaps its lowermost part) and reversed polarity (possibly lowermost part of the Mount Jefferson, as well as the tuff of Corcoran Canyon and unit C of the Bates Mountain Tuff), respectively. The southeast part of the caldera near its margin shows a broad magnetic high of more than 1,000 nT locally, likely related to the high induced and remanent magnetization of some of the ash-flow tuffs; content of opaque oxide minerals (probably mostly magnetite) is as much as 5 percent in some of the tuffs (Shawe, 1999b). Some tuffs in the area are sufficiently magnetic to deflect a Brunton compass needle. Other magnetic highs of more that 1,000 nT correlate with high terrain at Jefferson Summit just west of the Soldier Spring fault. Magnetic highs also form an alignment parallel to northwest-striking faults near the north boundary of the map, such as faults bounding the Corcoran Canyon graben. One northwesterly string of positive anomalies lies mostly west of the Soldier Spring fault, but it also extends to the east across the fault. It possibly is a reflection of buried structure related to the mapped northwest-striking faults. A residual magnetic map “illuminated” from the northeast (fig. 2) strikingly illustrates a dominant northwesterly structural grain within the Mount Jefferson caldera. The caldera is marked by several prominent northwesterly zones that may represent in part a set of fracture-controlled vents through which ash-flow tuffs erupted during collapse of the caldera. Such vents and related intrusions would be buried beneath caldera fill, and no evidence at the surface indicates their existence.

A pronounced negative magnetic anomaly with a minimum value of less than –300 nT lying outside the southeast margin of the caldera (margin established by the magnetic map, Map A, and corroborated by geologic mapping) coincides in large part with outcrop of the tuff of Corcoran Canyon, a unit of reversed polarity (C.S. Grommé, written commun., 2002). The magnetic data clearly show the distribution of this tuff unit.

Pronounced magnetic lows in the west part of the Mount Jefferson caldera in the Jefferson quadrangle may be related to a variety of features. A significant low (amplitude greater than 150 nT) lies between a rhyolite plug and the Jefferson Canyon fault. A fission-track date of 25.9±1.1 Ma on zircon from hydrothemally altered tuff of Mount Jefferson south of the plug has been interpreted as the age of the plug (Shawe and others, 1986) and alternatively as the age of alteration of the tuff (Shawe, 2003). However, the fission-track date instead may represent a reset age by reheating related to a younger intrusion. The strong negative anomaly may be related to either the plug or a second subsurface intrusion south of the plug, thus indicating that the body responsible for the anomaly is reversely polarized. Geologic relations show that the plug and inferred subsurface intrusion are younger than the tuff of Mount Jefferson, and thus must have been intruded during a period of reversed magnetism younger than about 26.8 Ma. One possibility is that it was intruded during the period of reversed polarity at about 23.7 Ma, at the time of eruption of unit C of the Bates Mountain Tuff. This possibility seems unlikely because magmatism related to the Mount Jefferson caldera as much as 3 million years following formation of the caldera seems unlikely . Alteration of the tuff of Mount Jefferson destroyed contained magnetite (Shawe, 1999b), which may be in part responsible for the magnetic low. Also, as previously suggested, a magnetic low associated with megabreccia necks and dike and altered rocks in the northeast part of the Round Mountain pluton southeast of the Jefferson district may be in part related to reversely polarized intrusions below the surface.

Two prominent northwest-trending negative magnetic anomalies (–100 to as low as –300 nT) are evident in the northwest part of the Mount Jefferson caldera within the map area (Map A). Possibly they reflect reversely magnetized subsurface intrusions related to eruptions of reversely magnetized tuff following development of the caldera. Because the long axes of these negative anomalies are aligned northwesterly, emplacement of intrusions may have been related to deep northwest-striking structures in the area. Areas of sheared ash-flow tuff coincident with or near the two negative magnetic anomalies have been interpreted as suggestive of subsurface intrusions that differentially lifted overlying tuff (Shawe, 1999b).

A prominent magnetic low just east of the Soldier Spring fault may be related to reversely polarized unit C of the Bates Mountain Tuff, which is probably present in the area beneath thin alluvial cover. Unit C of the Bates Mountain Tuff was shown by McKee (1976) to be equivalent to ash-flow tuffs described by Sargent and McKee (1969) as having reversed magnetism.

A strong gravity high (amplitude about 10 mGal) above volcanic rocks 3 km northeast of the Round Mountain mine suggests a buried intrusion. The possibility that some mineralization along the Jefferson Canyon fault just to the northeast was related to such an inferred intrusion is suggested in a later section.

Paired magnetic highs (20 to 80 nT) that lie just south of the Round Mountain gold-silver mine form an east-west magnetic ridge that may represent buried intrusive rocks beneath alluvium and volcanics. These magnetic highs lie close to the structural margin of a caldera mostly underlying alluvium of Big Smoky Valley (Henry and others, 1996). Mineralization of the Round Mountain deposit may have been related to the inferred intrusions.

The Manhattan caldera is characterized generally by a magnetic signature range of –20 to 60 nT. The relatively weak magnetic signature compared to that of the Mount Jefferson caldera may be related to a lower magnetite content of the tuffs that make up the caldera fill, coupled with more extensive areas of hydrothermally altered rocks. A broad magnetic high is centered at the north edge of an andesite stock (Crone Gulch Andesite) intruded into the ash-flow tuffs that fill the caldera. The west part of the stock corresponds to a topographic high, which may be responsible for the anomaly because of magnetic terrain effects (Grauch and Campbell, 1984). However, there is no correlation between the magnetic high and topography in the east part of the stock. Inasmuch as the andesite appears to be nearly devoid of opaque oxide mineral, including magnetite, and thus probably not significantly magnetic, the magnetic high associated with the stock may be related to a buried source proximal to the stock, possibly a second intrusion. A subtle gravity high (–26 to –24 mGal) coincides with the east end of the stock; although only a single-station anomaly, its association with the magnetic high suggests that it too is a response to the presence of an andesite stock. A southeast-trending magnetic low (20 to –20 nT) extends into the caldera from its northwest edge, centered on a set of northwest-striking, thin, gold-bearing quartz veins and a zone of gold-mineralized volcanic rocks (Shawe, 2003). The magnetic low may be related to terrain effects but it may in part reflect a zone of hydrothermal alteration. A cluster of small andesite plugs lies within the southeasterly negative magnetic anomaly, and these plugs are centered on a local gravity high (–22 to –18 mGal). The small andesite plugs may stem from a buried andesite stock, which if true could reflect an association of gold mineralization and the inferred stock. Farther to the northeast, an east-southeast-trending magnetic low (–60 to –20 nT) lies near a second cluster of small andesite plugs. The residual magnetic map “illuminated” from the northeast (fig. 2) shows, as in the Mount Jefferson caldera, a prominent northwesterly grain that may reflect zones of eruption of ash-flow tuff within the Manhattan caldera.

An east-trending magnetic high (as much as 150 nT) in the extreme southeast part of the map area may be related partly to an arc of rhyolitic flow domes, concave to the north, interpreted to be emplaced along the south structural margin of a caldera inferred to underlie the south end of Monitor Valley (Shawe and Byers, 1999). Conversely, the flow domes could be related to the Big Ten Peak caldera to the south because the trend of magnetic highs is concave to the south, as though controlled by the margin of a caldera lying to the south. More detailed geophysical and rock property data are needed to understand the relationship of geophysical anomalies and caldera structure.

Farther west, in the southeast corner of the Belmont West quadrangle and southwest corner of the Belmont East quadrangle, an arc of magnetic highs (from 20 nT to 150 nT) coincides closely with large remnant exposures of Isom-type ash-flow tuff, a magnetite-rich rock as determined by modal analyses of several thin sections (Shawe, 1998; Shawe and Byers, 1999). Elsewhere in the map area exposures of Isom-type tuff (not shown) are apparently too small to be resolved by the magnetic data.

Volcanic rocks exposed between the upper end of Ralston Valley and west side of Monitor Valley to the east (lat 38°37'30") apparently are nonmagnetic or form only a thin layer, as they do not appear to affect the magnetic field. Other volcanic rocks, especially in the southeast part of the map area, uncertain sources of which lie beyond the map area, are associated with magnetic values from 150 nT to –220 nT. Lack of information on magnetic properties (magnetite content as well as magnetic polarity) of these probably thin volcanics, as well as uncertainty regarding rocks that underlie the volcanics, hinder an assessment of these magnetic values.

EVALUATION OF AREAS OF QUATERNARY ALLUVIUM

Alluviated valleys (Big Smoky, Ralston, and Monitor Valleys) are marked by magnetic values (–300 nT to 200 nT) that reflect largely the magnetic character of rocks underlying effectively nonmagnetic alluvium. These rocks are probably the same as those characterizing the adjacent ranges: Paleozoic rocks, Cretaceous granite, and Tertiary volcanics. Also, the margins of the valleys, that is, the principal Basin-range fault boundaries of the valleys, generally coincide with magnetic and gravity discontinuities or alignments. The range-bounding faults along the east front of the Toquima Range are especially well manifested in the residual magnetic map “illuminated” from the southeast (fig. 3).

Some speculation as to the source of the magnetic values over alluvium may be warranted. As previously mentioned, the extreme magnetic low (to less than –300 nT) over alluvium in Monitor Valley just east of the margin of the Mount Jefferson caldera may represent reversely magnetized ash-flow tuffs underlying alluvium, possibly the tuff of Corcoran Canyon or the lower part of the tuff of Mount Jefferson. A broad magnetic high (as much as 100 nT) in Monitor Valley southeast of the Mount Jefferson caldera may represent a thick section of ash-flow tuffs similar to those exposed in the Toquima Range south of the Mount Jefferson caldera, probably the normal-polarity upper part of the tuff of Ryecroft Canyon. A small part of the Ryecroft Canyon crops out on the valley side of the nearby range-front fault bounding the older tuff of Corcoran Canyon (Shawe and others, 2000), showing that the Ryecroft Canyon has been dropped down east of the fault. In the south part of Monitor Valley a set of northeast-striking faults that cut alluvium flank a northeast-trending 0 to 40 nT magnetic high, possibly the trend of a structural ridge in bedrock. Because the gravity coverage is poor here, the ridge is not evidenced in the basement depth map.

NORTHWEST- AND NORTHEAST-TRENDING STRUCTURES

Reference was made earlier in this report to individual geologic features that are manifested on the residual magnetic maps "illuminated" from both the northeast (fig. 2) and the southeast (fig. 3). Broader aspects of the structural framework of the area are also evident.

The most striking aspect of the magnetic map illuminated from the northeast is indication of a northwest-striking structural grain that is present but less evident in the unfiltered data (Map A). The Mount Jefferson caldera especially is marked by several prominent zones that may represent a set of fracture-controlled vents through which ash-flow tuffs erupted during collapse of the caldera. Such vents would be buried beneath caldera fill, and no evidence at the surface indicates their presence. The Corcoran Canyon graben and other northwest-striking faults are marked by the northwest-trending magnetic zones. Major northwest-striking faults such as the Jefferson Canyon, Manhattan, and Hunts Ranch faults are reflected in the magnetic data. Other northwesterly magnetic trends in the south half of the map area suggest that some northwest-striking structures do not reach the surface. Within the Manhattan caldera, a northwest-trending magnetic zone is manifested at the surface by quartz veins.

The magnetic map "illuminated" from the southeast (fig. 3) enhances northeast-trending features and reduces the effects of northwest-trending features. Some northeasterly elements, interpreted to reflect a secondary set of the structural system of the area, appear within the Mount Jefferson and Manhattan calderas. Northeasterly trends are also prominent in the southeast part of the map, one element of which coincides with the northeast-trending set of faults mapped in alluvium in the south part of Monitor Valley.

The suggested northwesterly and northeasterly structures may be part of a regional conjugate system of northwest-striking and northeast-striking slip faults. Shawe and Byers (1999) and Shawe (2001) proposed that such fault patterns in the southern Toquima Range, some individual faults of which show appropriate offset, reflect regional wrench deformation involving northwesterly faults of right slip and northeasterly faults of left slip related to northwesterly movement of the Pacific plate relative to the North American plate, as is manifested also by the San Andreas–Garlock fault system in California and the Walker Lane system in Nevada. The range-front faults in the southeastern part of the southeast-illuminated magnetic map (fig. 3) are clearly shown.

DISCUSSION

Conclusions based on the magnetic and gravity maps fall into two categories: those pertinent to the geologic and structural character of the southern Toquima Range, and those related to mineralized zones, which therefore provide insight into mineralizing processes and mineral potential. The two aspects of course are interrelated; however, the following discussion will first summarize geologic and structural features and then relate geophysical interpretations to some specific mineralized zones, leading to inferences on mineralizing processes and controls (or deposit models) and qualitative mineral potential.

GEOLOGIC AND STRUCTURAL FEATURES

The magnetic and gravity maps together reflect many aspects of the geology evident at the surface. These include the general boundaries of the Round Mountain and Belmont plutons and the Tertiary Mount Jefferson and Manhattan calderas. The maps also emphasize specific geologic features such as the range-bounding faults along the southeast front of the Toquima Range, the Jefferson Canyon and Manhattan faults, the granodiorite stock intruded into the north part of the Round Mountain pluton, and the andesite stock (possibly a magnetic intrusion at depth related to the stock) intruded into the south part of the Manhattan caldera. An east-west structural zone marked by gravity and magnetic highs extends from the south margin of the Round Mountain pluton eastward into Monitor Valley. The magnetic maps reflect the northeast-striking set of faults in alluvium in the south part of Monitor Valley, reversely magnetized rocks near the Mount Jefferson caldera, an exposed serpentinite body near the east margin of Ralston Valley marked by a strong positive anomaly, and nearby positive anomalies farther east that reflect exposures of magnetite-rich Isom-type ash-flow tuff.

The residual magnetic maps "illuminated" from the northeast and from the southeast reveal a prominent northwesterly grain and a less prominent northeasterly grain, respectively, forming a conjugate system that dominates the southern Toquima Range. The elements of this pattern probably reflect the deep structural framework of the area. Some of the elements, both northwesterly and northeasterly, are evident at the surface in prominent faults: Jefferson Canyon and Manhattan faults (which also constitute the southwest margins of the Mount Jefferson and Manhattan calderas, respectively), Hunts Ranch fault, Soldier Spring fault, Corcoran Canyon graben faults, range-front faults at the southeast edge of the Toquima Range, and fault set in alluvium in the south end of Monitor Valley.

Some of the elements shown on the maps are slightly offset from their inferred corresponding structures at the surface (for example, aligned magnetic highs south of the Manhattan fault), and indicate dip of the structures. Other elements of the conjugate pattern are not evidenced at the surface (for example, northwesterly and northeasterly elements in both the Manhattan and Mount Jefferson calderas).

The magnetic character of the Cretaceous Round Mountain and Belmont plutons (magnetically high in their cores, magnetically low in their outer parts) is consistent with a laccolithic form, that is, they have rooted central stems and relatively thin lateral extremities. Initially magma may have been emplaced through a central conduit and it then spread laterally to form thick sill-like bodies. Doming of the plutons followed their emplacement, probably by renewed intrusion into their cores. Round Mountain pluton was intruded and domed by fine-grained granite. Concentric zonation of the two plutons may account for the lower magnetic response of their marginal parts, although this alternative possibility is not considered as likely as laccolithic form.

Initial uplift of what is now the core of the southern Toquima Range occurred probably in the Late Cretaceous, at the time of emplacement of the granite plutons. Judged from the presence of the Tertiary calderas exposed in the range, additional silicic magma may have been emplaced at depth just prior to caldera formation, causing additional uplift. The north-northeast- to northeast-trending margins of the southern Toquima Range, evident in the gravity data, are elements of the late episode of Basin-range tectonism and continuing uplift of the range.

The high-amplitude gravity lows over Monitor Valley and Big Smoky Valley indicate deep alluvial (and volcanic) fill, whereas the smaller amplitude gravity low over Ralston Valley probably reflects less fill, which is apparent in the basement depth map (fig. 5). The north end of Ralston Valley is a pedimented surface overlain by thin alluvium, and the valley likely formed as a result of headward erosion northward from a graben valley to the south.

MINERAL POTENTIAL

The geophysical data supplement geologic and geochemical data, described in earlier publications (see Shawe, 1988, 1995, 1998, 1999a, 1999b, 2003; Shawe and Byers, 1999; Shawe and others, 2000), in providing insight into the mineral potential of the southern Toquima Range. Besides reflecting structures related to important mineral occurrences that may have future potential (for example, Round Mountain gold-silver mine, Manhattan gold-silver district, Belmont silver district, Jefferson gold-silver district, and lesser mines such as the Red Bird Toquima, Van Ness, and Flower mercury mines, and Barcelona silver mine), the geophysical data suggest other areas where substantial mineral resources may yet be developed. In the following discussion, we speculate on environments favorable for undiscovered mineral deposits. The suggestions made demonstrate the utility of synthesizing geophysical, geochemical, and geologic data to indicate possible mineral targets. Evaluations are made on the premise that most mineralized zones in the southern Toquima Range resulted from thermal events, probably caused by igneous intrusions. The Round Mountain, Manhattan, Jefferson, and Belmont mining districts all possess indications of additional nearby mineral resources.

Several mineralized zones in the southern Toquima Range, of varied metal associations (see Shawe, 2003, for such zones not specified here), show no clear association with geophysical features. Their understanding does not appear to be aided by the present evaluation of geophysical data, and they are not discussed below.

At Round Mountain, aligned gravity and magnetic positive anomalies immediately south of the district suggest buried intrusions, possible sources of gold-silver mineralizing fluids that formed the Round Mountain deposit as well as yet undiscovered gold-skarn and gold-quartz-vein deposits in volcanic rocks near the intrusions. One intrusion may have been emplaced into Paleozoic rocks underlying a relatively thin layer of granite in the extremity of the Round Mountain pluton (fig. 6). Favorable lithologies in the Paleozoic section could host porphyry or other deposits of both base and precious metals.

At Manhattan, an aligned zone of magnetic highs subparallel to and mostly south of the Manhattan fault is suggestive of intrusions emplaced into the fault at depth. Several magnetic highs coincide with zones of tourmaline occurrence and (or) significant boron anomalies (indicative of tourmaline). The tourmaline association strongly suggests presence of a mineralizing (andesitic or granodioritic?) stock, especially in the vicinity of the White Caps mine. Age of emplacement of the inferred stock may be about 75 Ma or about 50–45 Ma (Shawe and others, 1986). Gold and associated mercury, arsenic, and antimony at the White Caps mine represent distal mineralization. Presence of minor amounts of base metals in the mineralized zone at the surface may indicate a porphyry deposit proximal to the inferred intrusion characterized by copper or copper and molybdenum. Gold-bearing skarn deposits also are possible (see Shawe, 1988).

Deposits of Miocene age in the Gold Hill mined area at Manhattan are geochemically much different from the older White Caps deposit. However, they are closely associated with a magnetic high in the aligned zone of anomalies; the magnetic high could represent a younger intrusion in the zone (devoid of tourmaline). Scarcity of other metals at the surface near the Gold Hill mined area argues against porphyry possibilities at depth, but perhaps gold-skarn or gold-quartz vein deposits may be present. Deposits of different ages and types coinciding with the northwest-trending zone of magnetic highs suggest that the associated structures have been episodically active to circulate mineralizing fluids.

Mineralized ground in the Jefferson district may include that associated with the early Oligocene granodiorite of Dry Canyon stock east of Round Mountain, extending into the district. Gold mineralization occurring south of a rhyolite plug (Shawe, 1988) surrounded by hydrothermally altered ash-flow tuff is marked by a strong negative magnetic anomaly. The anomaly probably reflects a reversely polarized subsurface intrusion, and possibly also the hydrothermally altered tuff. Additional gold mineralization may have occurred at depth. Just south of the area of gold mineralization, hydrothermal alteration and principal mineralization in the district took place along the Jefferson Canyon fault (Shawe, 1988). It was characterized by dominant silver, but significant other metals also are present (Shawe, 2003), raising the possibility of a porphyry system related to a buried intrusion. An inferred buried intrusion beneath volcanic rocks 3 km northeast of the Round Mountain mine may be related to some of the mineralizing activity in the Jefferson district. Although the district exhibits no aligned magnetic highs, as near the Manhattan fault in the Manhattan district, a pronounced elongate negative magnetic anomaly extends southeastward along the projection of the Jefferson Canyon fault, possibly related to a zone of hydrothermally altered granite or reversely polarized subsurface igneous bodies. The magnetic low also coincides with a northwest-striking megabreccia dike and several megabreccia necks intruded into granite. The southeasternmost neck is mineralized with fluorite veins and minor gold, antimony, and mercury (Shawe, 1999b). The zone of altered granite and megabreccia intrusions appears to be favorable for buried mineral deposits of unknown character. Such inferred deposits may be at shallow depth beneath the proposed thin peripheral part of the Round Mountain granite pluton. In addition to the geophysical evidence that granite is thin in this zone is the presence of clasts of metamorphosed Paleozoic sedimentary rocks and of andesite porphyry in the megabreccia intrusions that were brought up from beneath the granite. The Jefferson district exhibits aspects of multiple episodes of varied mineralization.

In the Belmont mining district, geologic and geochemical evidence indicates that silver-lead-molybdenum mineralization was related to the adjacent Cretaceous Belmont granite pluton (Shawe, 2003). But the additional occurrence of mercury, arsenic, and antimony that generally are associated with Tertiary mineral deposits in the southern Toquima Range raises the possibility of other mineralizing sources. A pronounced magnetic low just west of Belmont may indicate the presence of an intrusion of reversed magnetic polarity. However, the low may also indicate hydrothermal alteration adjacent to an intrusion beneath relatively thin granite in the periphery of the pluton.

In addition to possibilities of undiscovered mineral resources remaining in the productive districts of the area, several areas of minor or only negligible production of metals offer potential for mineral resources as suggested by geophysics. These include the Bald Mountain Canyon belt of small gold-quartz veins, the vicinity of the granodiorite of Dry Canyon stock east of Round Mountain, an east-trending zone characterized chiefly by mercury that extends from the southwest edge of the Round Mountain granite pluton to the vicinity of the Flower mercury mine, and an area of base-metal and silver mineralization in Paleozoic rocks about 4 km south of Round Mountain.

The northwest-trending Bald Mountain Canyon belt of small gold-quartz veins in the west part of the Manhattan caldera is marked by a positive gravity anomaly probably reflecting a buried andesite stock (a few small plugs of andesite are exposed in the area, Map B), and by a southeast-trending magnetic low (Map A) that may represent local hydrothermal alteration of the ash-flow tuffs filling the caldera. Although the magnetic low may be related to terrain effects, the gravity anomaly supports the inference of a buried stock and therefore the likelihood of hydrothermally altered ground. A continuous northwest-trending structure at depth may have fed mineralizing fluids into porous tuffaceous rocks to form a deposit or deposits analogous to the great Round Mountain gold-silver deposit.

The geophysically defined granodiorite of Dry Canyon stock east of Round Mountain and the mineralized granite surrounding it, especially on its southeast side, could be an environment conducive to porphyry mineralization in more favorable wallrocks. Boron and tourmaline halos (Maps A and B), as well as scattered base- and precious-metal veins, indicate widespread mineralization in the vicinity of the stock. The likelihood that favorable host lithologies in Paleozoic rocks underlie granite at shallow depth allows speculation that porphyry mineralization took place at greater depth. (Andesite dikes that cut granodiorite show that a stock younger than the granodiorite, and with possible associated mineralization, may have been emplaced at depth.)

In the vicinity of the Flower mercury mine, nearly coincident magnetic and gravity highs suggest a buried intrusion. A wide zone of significant boron mineralization indicative of the presence of tourmaline (Maps A and B), and anomalous metal values in the area, support this hypothesis. As in the area of the White Caps mine in the Manhattan district and at the granodiorite of Dry Canyon stock east of Round Mountain, a porphyry environment or another intrusion-related mineralized zone at depth is suggested.

The east-trending zone of mercury deposits lies along a more regional (unnamed) east-trending magnetic zone extending from the Mariposa Red Dog prospect to Monitor Valley. Because several known deposits correlate with this proposed 20-km-long zone, potential for other deposits exists. Structural control of the zone seems apparent, as suggested by linearity and length of the magnetic zone, and its position, in part, along the structural boundary between the Round Mountain and Belmont plutons. Magnetic or gravity highs associated with some of the deposits also indicate possible intrusion associations. Mineralogical evidence of more than one mineralizing event at the Outlaw and the Mariposa Red Dog prospects (Foord and others, 1988) indicates reactivation of the east-trending structural zone defined primarily by the magnetic data. Quartz veins at the two prospects dated as Late Cretaceous in age were remineralized with mercury minerals in Tertiary time (Shawe and others, 1986). The Barcelona silver mine, probably deposited initially in the Cretaceous, also contains anomalous mercury, probably of Tertiary derivation. Anomalous molybdenum in the vicinity of the Barcelona mine could be associated with a porphyry environment, but it more likely reflects contact metamorphism related to the adjacent Cretaceous Round Mountain granite pluton.

A strong positive gravity anomaly associated with Paleozoic rocks about 4 km south of Round Mountain is suggestive of a buried igneous intrusion. The anomaly lies at the southwest end of a swarm of rhyolite and minor andesite dikes that extends to and beyond the granodiorite of Dry Canyon stock east of Round Mountain (the dike swarm is not shown on Maps A and B). Presence of anomalous base metals and silver in the Paleozoic rocks (Shawe, 1988, 2003) are indicative of a significant mineralized system similar to others in the southern Toquima Range that are related to intrusions.

CONCLUSION

This study demonstrates the utility of regional geophysical data combined with geologic information in aiding exploration for mineral deposits in the southern Toquima Range. These data are not detailed enough to define targets, but they establish the regional geologic framework and allow interpretations of local environments that may be favorable for mineralized areas. Future research involving measurement of physical properties of rocks and rock units, followed by geophysical modeling, could lead to establishing genetic relations between endogenic ore deposits and the geophysically-interpreted crustal structures discussed here.

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