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Petrochemistry of Igneous Rocks, Silver City 1° × 2° Quadrangle, New Mexico and Arizona

By

William N. Sharp

INTRODUCTION

This part of the Silver City folio of the Conterminous United States Mineral Assessment Program (CUSMAP) assembles much of the petrologic and chemical data developed during the study of the quadrangle under the CUSMAP program. The study draws on basic investigations that indicate rock associations, variations in rock bodies, metasomatic aspects, age relations, and associated known mineral deposits.

Most of the metallic mineral deposits in the Silver City 1° × 2° quadrangle are spatially and genetically related to a number of granitic plutons and silicic eruptive centers of Mesozoic and Cenozoic age. In resource assessments, all intrusive rocks and eruptive systems, regardless of known metal associations or ore deposits, should be considered possible sources of metals. The petrochemical aspects of the exposed surface rocks yield important clues as to the nature of the buried magma chamber and the economic potential of the system. This study of the intrusive rocks and some of the eruptive centers in the Silver City quadrangle uses modern models of granitic and volcanic rock evolution to demonstrate where conditions may have been favorable for the concentrations of ore minerals.

The accompanying map of the Silver City 1° × 2° quadrangle (sheet 1) shows the exposed granitic plutons and silicic eruptive centers discussed in this report. In table 1 (sheet 1), these granitic plutons and eruptive centers are grouped into age intervals, and in table 2 (sheet 1), each sample is listed under the pluton or eruptive center it represents and is briefly described. Tables 3, 4, and 5 (sheet 2) list the major-element chemistry, accessory-mineral assemblages, and minor-element chemistry from which the petrologic and chemical character of the intrusive and extrusive rocks can be derived. The Rb/Sr versus Zr/Nb ratios shown on figure 1 (sheet 2) are derived from the minor-element data.

Major objectives of this study were the following: (1) to determine the possibility that the magmatic systems host metal concentrations and perhaps ore deposits such as copper or molybdenum porphyries, molybdenum stockworks, and tin-tungsten granite systems, some perhaps with peripheral veins or base-metal replacements; (2) to identify intrusive rocks that have rare-earth element (REE) and rare-metal by-product potential for elements such as niobium (Nb), tantalum (Ta), uranium (U), and scandium (Sc); and (3) to examine the volcanic eruptive centers in an attempt to determine the degree of magma maturity and associated metal enrichment in the buried source magma chambers.

ROCK CHEMISTRY AND AGE GROUPINGS

Most of the intrusive rocks in the Silver City quadrangle are granites, granodiorites, tonalites, and monzonites (nomenclature after Streckeisen, 1976). Gabbro, diorite, monzodiorite, and quartz syenite are associated in one complex. Two massive dikes within the Gillespie pluton and the subvolcanic mass at Saddle Peak are alkali-feldspar granite (rhyolite). The zoned pluton at Pinos Altos is unusual in that it ranges from syenodiorite (nomenclature after Jones and others, 1970) in the border phase to granite in the core.

The post-Paleozoic history of intrusive and volcanic activity in the study area began during the Late Cretaceous, which in popular tectonic models relates to a surge in the eastward transgression of the Laramide magmatic arc—an arc associated with the subduction of a Pacific plate (Coney and Reynolds, 1977; Damon and others, 1981). This time interval, generally referred to as the Laramide or Cordilleran orogeny, is the period when many porphyry copper deposits as well as peripheral massive replacement deposits of copper, zinc, lead, and iron were formed in the area. The Laramide interval was followed by a magmatic quiet period or intrusive hiatus (50–40 m.y. ago).

Petrochemical analyses of intrusive and volcanic rocks in the quadrangle show that their compositions changed from the Late Cretaceous to the late Tertiary. Compositions of Late Cretaceous (80 m.y.) to middle Eocene (50 m.y.) intrusions are mostly granites and granodiorites that are cogenetic with andesitic and dacitic volcanic rocks of medium-K, calc-alkaline affinity. Late Eocene to late Oligocene (40–26 m.y.) rocks show the beginnings of changes to higher silica, more alkalic types, transitional to the high-K volcanic rocks erupted through part of the late Oligocene to early Miocene (26–18 m.y.). These youngest eruptive rocks, occurring chiefly as flows, domes, and associated dike swarms may be products of high-level, zoned magma chambers.

Assuming that the composition of the eruptive rocks expresses the composition of the magma below and that magmas possibly develop into chemically zoned bodies, we may infer that the eruptive rocks represent the petrochemical character of the upper parts of magma chambers. The compositional change from the Laramide calc-alkaline granites to the Tertiary high-K, high-silica igneous complexes represents a transition from compressional tectonism to extensional tectonism—a possible consequence of an abrupt change in the dip of the subducting plate and a rapid regression of the magmatic arc from its most eastward transgression into what is now western New Mexico (Coney and Reynolds, 1977).

Shaw and others (1976) used the theory of thermogravitational diffusion to explain the development of chemically zoned magma chambers. Hildreth (1979) and Smith and McDonald (1979) further demonstrated the existence of major-, minor- and trace-element gradients between the early and late parts of multi-episode silicic eruptions. Some important metals are concentrated in the upper parts of zoned magma chambers, and others may be associated with certain granitic variants in other parts of zoned systems. Within the study area, thermogravitational diffusion rather than simple crystal fractionation may account for some of the observed sequences of compositional zoning in granitic intrusions and also for the sequence of chemically diverse lavas erupted from some of the silicic eruptive centers. The petrochemical data in this report are used as a tool for evaluating the degree of evolution of a specific system and, consequently, the possibility of a specific metal commodity being present at significant levels of concentration.

The upper zones of evolved granitic magmas are more silicic, are biotite and ilmenite bearing, and are measurably enriched in K, Rb, Nb, F, and U, and locally enriched in Sn, W, Mo, Y, Th, Be, and rare-earth elements. If zoned and evolved granitic magmas vent to the surface, the early eruptive rocks tend to be highly silicic and potassic, enriched in Rb and Nb, and depleted in Sr and Zr. In addition, post-magmatic, fissure-vein systems containing elements such as Sn, W, Mo, U, Th, F, and rare-earth elements may be associated with these eruptive rocks.

The elements Rb, Sr, Zr, and Nb, which form consecutive pairs in the periodic table, appear to be especially useful in deducing the nature of the differentiation process in a magma chamber, as well as the degree of maturation of the magma. In erupting lavas from evolving magmatic systems such as the Bishop Tuff (California), the Valles Rhyolite (New Mexico), and the rhyolites of the Coso Formation (California), these elements exhibit pronounced and consistent changes (either enrichment or depletion) with time. Figure 1 (sheet 2) utilizes these four elements in a log Zr/Nb versus log Rb/Sr diagram (after Steve Ludington, unpubl. data) to examine the mineral resource potential of the granitic and silicic eruptive rocks of the Silver City quadrangle. Figure 1A, for example, illustrates how granitic rocks with known metal associations plot on a log Zr/Nb versus log Rb/Sr diagram. Rocks from rare-metal-enriched, upper parts of zoned magma chambers, such as tin-granites and plutons associated with most molybdenum deposits, have log Zr/Nb less than 1 and log Rb/Sr greater than 0. In contrast, rocks from unzoned magma chambers, or the lower, deeper parts of zoned magma chambers, such as plutons associated with porphyry copper deposits, have log Zr/Nb greater than 1 and log Rb/Sr less than 0. The broad shaded line shown in all the diagrams of figure 1 represents the trend of the Zr/Nb and Rb/Sr ratios in the Bishop Tuff (Hildreth, 1979), going from least evolved magmas (lower right) to most evolved magmas (upper left).

ACCESSORY MINERALS

In addition to whole-rock trace-element data, accessory minerals may also show the degree of compositional development in a magma chamber. For example, the presence of high levels of fluorine in biotite and apatite, manganese in garnet, and niobium in ilmenite, and the presence of minerals such as Li-mica, cassiterite, uraninite, ilmenorutile, and other rare multiple oxides strongly infer chamber zoning and, therefore, a certain resource potential. In general, accessory mineral aspects to be noted include (1) the presence of black multiple oxides and complex oxides; (2) fluorite in accessory assemblages, as well as the presence of yttrium (Y) and cerium (Ce) in the fluorite; and (3) the halogen ratios in certain accessory minerals such as mica, apatite, and amphiboles.

Granitic complexes that contain ore deposits seem to have specific accessory-mineral assemblages that are diagnostic of the associated ore system. In molybdenum-stockwork systems, common diagnostic accessory minerals include ilmenorutile, fluorite, F(Ce)-apatite, columbite, Th-monazite, and aeschynite. In tin-granite systems, common accessories are ilmenorutile, rutile, cassiterite, uraninite, fluorite, and REE minerals. Pyrochlore-granites usually have conspicuous accessory minerals containing sodium, such as Na-amphibole and astrophyllite, and may have fluorite and Nb-ilmenite in addition to pyrochlore. Copper porphyry systems, on the other hand, generally contain abundant allanite, magnetite, sphene, and Cl-rich apatite.

Multiple and complex oxides, such as ilmenorutile, aeschynite, brannerite, columbite, euxenite, and similar oxides that contain a variety of cations, seem to be good signal minerals for some types of mineral deposits and may even constitute a resource themselves (Desborough and Sharp, 1978). Of these minerals, ilmenorutile is the phase that is most commonly observed in intrusive rocks that are associated with molybdenum ore deposits and silicic tin-granites. Ilmenorutile is chiefly a TiNbFe oxide but, in unaltered granitic rocks, it and the similar mineral aeschynite seem to have a great capacity for accumulating small amounts of important rare metals. Besides the dominant Nb and Ti, ilmenorutile may contain varying amounts of Ta, Y, U, Th, Sn, and Sc. On detailed examination, some of these components form exsolved phases within the ilmenorutile, phases such as uraninite, columbite, and brannerite. Other oxides may act similarly. Columbite may contain Ta and Sc in separate phases such as uraninite; thorite may have uranium-rich areas; euxenite may have Ta in its structure; ilmenite may contain exsolved columbite and rutile; and monazite may have phases unusally rich in Th and U.

The importance of these accessory minerals is that small amounts of rare metals detected or measured in whole-rock analyses are generally present in a single phase, such as oxides, of the accessory mineral assemblage. The oxide phase is easy to separate out and, when rocks containing oxides are mined in a large-tonnage operation (10–50 thousand tons per day), the rare metals may constitute a significant and valuable by-product.

VOLCANO-PLUTONIC SYSTEMS FAVORABLE FOR ORE METALS

On the basis of minor element content and compositions of accessory mineral assemblages, several granitic plutons and silicic eruptive centers in the Silver City quadrangle show characteristics of zoned magma chambers. These volcano-plutonic systems, which are described in more detail below, are considered favorable environments for the deposition of certain ore minerals and warrant further study.

ASH PEAK-RHYOLITE PEAK ERUPTIVE CENTER

The Ash Peak-Rhyolite Peak eruptive center of mid-Tertiary age (24–21 m.y.) consists chiefly of rhyolite domes, lava flows, and minor rhyolitic, air-fall and ash-flow tuffs. The rhyolites are peraluminous to slightly peralkaline, high in SiO_2 (75–77 percent) and K_2O, and low in CaO and MgO. The Rb/Sr ratio is very high. Biotite, allanite, ilmenite, and Ti-magnetite are common accessory minerals; some rock units contain fayalite. Nb is anomalously high throughout the eruptive complex. Log Zr/Nb versus log Rb/Sr plots shown on figure 1C are within the range of early eruptive phases of the Bishop Tuff sequence and that of known evolved silicic stocks such as the Climax and Henderson molybdenum systems (fig. 1A).

Fissure veins near the Ash Peak system, which are probably related to the silicic volcanism, are filled with quartz, calcite with black manganese oxides, and copper, silver, and lead sulfides. In addition, stream-sediment pan concentrates from around Ash Peak contain cassiterite, fluorite, and anomalous concentrations of Nb, Zn, Ba, and Bi in the heavy fractions.

These petrologic, chemical, and mineralogical features suggest the presence of a pluton at depth that had the maturity to develop phases rich in molybdenum, tin, and other rare metals. The eruptive center is a preferred target for further investigations and exploration.

TOLLGATE WASH ERUPTIVE CENTER

The Tollgate Wash eruptive center is a silicic volcanic pile somewhat younger than the nearby Ash Peak-Rhyolite Peak center. It differs from the Ash Peak center in that two chemically distinct rhyolites are present: a low-silica (71 weight percent SiO_2), crystal-rich phase that forms an extensive dome-flow apron; and a high-silica (77 weight percent SiO_2), crystal-poor central dome. All the rocks are peraluminous, and the high-silica phase is low in Ca and Mg. Biotite, ilmenite (locally Nb-bearing), and fayalite are common accessory minerals; fluorite and fluorapatite are locally present. Stream-sediment pan concentrates contain cassiterite, fluorite, magnetite, and ilmenite.

Plots of log Zr/Nb versus log Rb/Sr ratios for the Tollgate Wash center (fig. 1C) have a position typical of magmas high in a well-developed zoned chamber that may host molybdenum, beryllium, and tin. The Tollgate Wash area is considered a prime target for further investigation and possible exploration.

GRANITE GAP PLUTON

The Granite Gap pluton is a leucogranite stock (32–30 m.y.) that intrudes Precambrian granite and Paleozoic limy sedimentary terrane. The pluton may be a moderately high-silica phase of a large volume granite body at depth. Associated dikes range from granite porphyry to rhyolite and quartz latite. An array of accessory minerals, some uncommon (see table 4), occurs in the stock and its late-stage metasomatized border zone. Skarns containing small deposits of copper, lead, zinc, silver, and tungsten are developed in the Paleozoic limestone. Fluorite is not found in the granite but does occur in a porphyry border phase, dikes, and associated fissure veins.

The granite is peraluminous, ranges from 73 to 76 weight percent SiO_2, and consists of as much as 4.5 weight percent K_2O and 2.5 weight percent Na_2O. A large number of accessory minerals are present, including Nb-ilmenite, ilmenorutile, U and Th minerals, complex oxides of Nb, Y, and Ti, and REE phosphates. Zircon is common; two types occur in late-stage rocks. One zircon is colored and contains high Th; the other is clear. This assemblage could, in part, represent the assimilation of subjacent Precambrian granite.

The leucogranite is relatively high in Nb and Rb, and stream sediments derived from the pluton have anomalously high contents of Pb, Zn, Bi, and F. Molybdenum is present in wulfenite in accessory mineral assemblages.

In the plots of log Zr/Nb versus log Rb/Sr ratios, the Granite Gap pluton occupies a field in the upper part of the slope of evolving systems (fig. 1*B*). It has many of the criteria of intrusive rocks that contain molybdenum-rich systems and ore bodies; however, erosion may have removed any cupola accumulations of metals. Regardless, the Granite Gap pluton is a target for further study and possible exploration.

WHITE SIGNAL ERUPTIVE SYSTEM

The White Signal system includes a number of small, middle Tertiary rhyolite plugs and several rhyolite dike swarms peripheral to a granite of Laramide age (50 m.y.) at Tyrone. The various intrusive units include the rhyolite plugs at the Shrine center (29–28 m.y.), the cluster of rhyolite plugs around White Signal, and the rhyolite fissure dikes of possibly earlier age (42–41 m.y.) that trend northeast in swarms north and south of the Tyrone stock.

The White Signal and Shrine plugs and associated dikes have metal deposits and petrologic characteristics that strongly suggest probable development of metal systems in the subsurface. The rhyolites are high-silica, high-K varieties, enriched in Rb and Nb, and are associated with fissure-veins containing F and U, and locally Mo.

The stream sediments of the area show anomalous abundances of metals that are characteristic of molybdenum systems as well as copper systems, but the close proximity of the Tyrone copper-molybdenum porphyry system of Laramide age confuses the geochemical picture.

Plots of log Zr/Nb versus log Rb/Sr ratios of the White Signal system (fig. 1E) cluster near that of Granite Gap, Ash Peak, and Tollgate Wash centers. The data show no significant variation in the Zr/Nb ratio but do show a range of Rb/Sr values.

The data for the White Signal-Shrine plugs and dike system suggest that there may be a granite-molybdenum system at depth, and, in fact, recent drilling at White Signal reportedly has encountered molybdenum-bearing rocks. The Shrine area and the remainder of the dike swarm around the west periphery of the Tyrone stock have not been carefully examined or explored.

VICTORIO MOUNTAINS INTRUSIVE ROCKS

The small rhyolite porphyry plugs and dikes (24.8 m.y.) in the Victorio Mountains suggest that a much larger granitic body underlies the area at shallow depth. The terrane consists chiefly of layered Paleozoic and Mesozoic sedimentary rocks and Cenozoic dacitic flows. The intrusive porphyries are high in SiO_2, enriched in Rb and Nb, and depleted in Sr and Zr (fig. 1B), and in places are metasomatized to a Li-muscovite rock. Quartz veins and small replacement deposits containing Pb, Zn, W, Be, Sn, and Mo minerals are spatially and apparently genetically related to the rhyolites. The quartz veins and some of the replacement deposits in contact zones in the vicinity of the rhyolite bodies have been mined, and some tungsten has been produced. In addition, silicified Paleozoic carbonate rocks and base-metal-rich replacement deposits occur about 1 ½ km from the surface cluster of rhyolite bodies. These deposits and the associated silicified rocks are anomalously high in Sn, Mo, and B; these data, coupled with presence of quartz veins, and the character of the rhyolites suggest venting from a highly evolved magma at shallow depth.

The stream-sediment concentrates are also suggestive of mineralized systems of greater extent than appears at the surface. Concentrates show anomalous amounts of W, Cu, Zn, Ba, Ag, Bi, and F, all excellent indicators of an evolved magma body having potential for metal resources in molybdenum, copper, and tin. Although molybdenite as a mineral phase has not been detected, the area is considered favorable for a molybdenum porphyry deposit and a good site for further study for other metal resources.

YORK VALLEY-STEEPLE ROCK ERUPTIVE SYSTEM

Two centers of igneous activity in the Summit Mountains in the north-central part of the quadrangle are considered areas of potential mineralization. One center at Carlisle and Steeple Rock is characterized by a swarm of large rhyolite fissure dikes that cut andesitic to dacitic lavas and rhyolite ash-flow tuffs. These dikes follow a northwest zone of faults, some of which contain base- and precious-metal-bearing quartz veins and altered zones. The second center is at York Valley (Twin Peaks-Saddleback Mountain), about 6–7 km to the northwest. This center is also characterized by rhyolite dikes, a scattering of rhyolite plugs, and a fault system filled locally by quartz veins. Over a large area, siliceous tuffaceous sediments near the locus of the dike swarm were altered by acidic solutions to alunite. F- and Mn-bearing fissure veins occur in the outer halos of both centers, and anomalously high radioactivity is associated with some of the small peripheral rhyolite plugs.

The accessory minerals for this area have not been examined. The rhyolites, where analyzed, are high silica (73–78 weight percent SiO_2), enriched in Rb and Nb, and depleted in Sr and Zr (fig. 1E). The mineral components in the various veins indicate high F, Mn, Ag, Cu, and notable Be and U for the system.

Stream-sediment pan concentrates also support the evolved character of these centers with anomalous Sn, Cu, Ba, Ag, and F. Molybdenum has not been noted but is suspected to be present, particularly in the Cu, base-metal, Ag, and Au veins in the area.

GREASEWOOD MOUNTAIN ERUPTIVE CENTER

The Greasewood Mountain eruptive center (24 m.y.) consists of interbedded ash flows and flows of latite and rhyolite and volcanic conglomerate. A late swarm of quartz latite dikes, which postdate (22.9 m.y.) the eruptive center, trends northeastward in a broad belt away from the center. The dike system shows major- and minor-element characteristics generally associated with granite-molybdenum systems. The dikes are high-silica, high-K rhyolites, enriched in Rb and depleted in Sr and Ca. They are noticeably radioactive and contain Y-fluorite and REE-fluorite as accessory minerals. In addition, sediments from streams draining the late stage dikes, and the volcanic center in general, contain anomalous concentrations of Mo, F, and U that may signal a granite-metal system at depth.

Six phases of flows from the Greasewood center show a considerable range in Rb/Sr ratio values and virtually no spread in Zr/Nb ratio values, which suggests a lack of chamber maturing or compositional zoning in the source chamber (fig. 1F). However, as the early flows are higher in Rb than the late flows, there is some indication that zonation was beginning.

The late fissure-filling quartz latite dikes are more highly evolved. Plots of log Zr/Nb versus log Rb/Sr ratios (fig. 1F) for these rocks define a field having relatively high Nb values (low Zr/Nb ratios), thus suggesting that a late magma (22.9 m.y.) had significantly matured. The Rb/Sr ratio ranges widely, but the increase in Nb relative to Zr is conspicuous. The presence of uranium (radioactivity) may also be significant and indicative of venting from an evolved, zoned magma. The Greasewood Mountain eruptive center seems a good target for further study.

STEINS ERUPTIVE CENTER

The Steins eruptive center is an eroded, intermediate to silicic, eruptive complex (35–31 m.y.) about 16 km across, with rhyolite ring domes surrounding a shallow caldera that was intruded by a late rhyolite plug. Small Ag-bearing fissure veins are locally present.

The rocks in the eruptive center range from dacite to low-silica rhyolite (64–72 weight percent SiO_2). Samples from early flows compared to late flows show an increase in Rb/Sr and a slight decrease in Zr/Nb. The ring dome rhyolites, emplaced after development of the caldera, show a wider range in Rb and some characteristics common to bimodal rhyolites. Plots of log Zr/Nb versus log Rb/Sr ratios (fig. 1D) for the late rhyolite plug show a negative sloping field with low Rb and relatively high Zr/Nb ratios. Neither the minor-element distribution, stream-sediment mineral concentrates, nor the minerals of the accessory assemblages show any indication of maturity or zonation in a magma chamber.

Small Ag-bearing carbonate veins occur both in the ring fracture zone of the caldera and in a graben related to a small resurgent dome within the caldera. This mineralization is typical of venting from a homogeneous, low-silica granite magma. The Steins eruptive center does not appear to be a target for metal deposits associated with evolved magma chambers.

RHYOLITE CANYON FORMATION

The Rhyolite Canyon Formation (26–25 m.y.) is the main ash-flow sheet from the Turkey Creek caldera, an eruptive center lying mostly outside the Silver City quadrangle. The ash flows exposed in the quadrangle consist of high- to moderately high-silica rhyolite. A large volume of intermediate composition flows is associated with the center, and a low-silica granite pluton is exposed in the caldera to the south. The rhyolites have high Rb and Nb and low Sr contents and contain rhombic hematite, Nb-ilmenite, and fluorite as accessory minerals. Log Zr/Nb versus log Rb/Sr ratios (fig. 1C) for the Rhyolite Canyon Formation is a small field near the upper end of the sloping trend of evolved granitic systems, close to the fields for Ash Peak and Tollgate Wash eruptive centers and within the range typical of molybdenum-stockwork deposits (fig. 1A).

Stream sediments from the terranes of these deposits contain rhombic hematite, ilmenite (some Nb-bearing), cassiterite, and fluorite. The analyses of the pan concentrates show anomalously high values for Pb, Zn, and Ba. Minor tin prospects occur in the terrane of these eruptive rocks, but no developed mining or mineralized areas are known. However, the evidence suggests that an unexposed granitic magma phase that could produce a granite-molybdenum system may be present. The area is considered a good target for further evaluation.

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REFERENCES

Coney, P.J., and Reynolds, S.J., 1977, Cordilleran Benioff zones: Nature, v. 270, p. 403–406.

Damon, P.E., Shafiqullah, M., and Clark, K.F., 1981, Age trends of igneous activity in relation to metallogenesis in the southern Cordillera: Arizona Geological Society Digest, v. 14, p. 137–154.

Desborough, G.A., and Sharp, W.N., 1978, Tantalum, uranium, and scandium in heavy accessory oxides, Climax molybdenum mine, Colorado: Economic Geology, v. 73, p. 1749–1751.

Ewart, A., 1979, A review of the mineralogy and chemistry of Tertiary-Recent dacitic, latitic, rhyolitic, and related salicic rocks, *in* Barker, F., Trondhjemites, dacites and related rocks: Amsterdam, Elsevier, p. 13–121.

Hildreth, W., 1979, The Bishop Tuff—Evidence for the origin of compositional zonation in silicic magma chambers: Geological Society of America Special Paper 180, p. 43–75.

Jones, W.R., Moore, S.L., and Pratt, W.P., 1970, Geological map of the Fort Bayard quadrangle, Grant County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–865, scale 1:24,000.

Mutschler, F.E., Wright, E.G., Ludungton, S., and Abbott, J.T., 1981, Granite molybdenite systems: Economic Geology, v. 76, p. 874–897.

Shaw, H.R., Smith, R.L., and Hildreth, W., 1976, Thermogravitational mechanisms for chemical variations in zoned magma chambers: Geological Society of America Abstracts with Programs, v. 8, no. 6, p. 1102.

Smith, R.L., 1979, Ash-flow mechanism: Geological Society of America Special Paper 180, p. 5–27.

Smith, R.L., and McDonald, Ray, 1979, Rhyolitic volcanism and its relationship to granitic plutonism: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 520.

Streckeisen, A., 1976, To each plutonic rock its proper name: Earth Science Review, v. 12, p. 1–33.

Watts, K.C., and Hassemer, J.R., 1980, Distribution and abundance of fluorite in stream-sediment concentrates, Silver City 1° ×2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183–C, scale 1:500,000.

Watts, K.C., Hassemer, J.R., Forn, C.L., and Siems, D.F., 1986, Geochemical maps of lead in stream-sediment concentrates, Silver City 1°×2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183–A, scale 1:500,000.

______ 1986, Geochemical maps of copper in stream-sediment concentrates, Silver City 1°×2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183–B, scale 1:500,000.

______ 1986, Geochemical maps of zinc in stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183–D, scale 1:500,000.

______ 1986, Geochemical maps of molybdenum in stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183–E, scale 1:500,000.

______ 1986, Geochemical maps of silver in stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183–F, scale 1:500,000.

______ 1986, Geochemical maps of tungsten in stream-sediment concentrates, Silver City 1° ×2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183–G, scale 1:500,000.

______ 1986, Geochemical maps of bismuth in stream-sediment concentrates, Silver City 1° ×2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183–H, scale 1:500,000.

______ 1986, Geochemical maps of tin in stream-sediment concentrates, Silver City 1° × 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183–I, scale 1:500,000.

______ 1986, Geochemical maps of manganese in stream-sediment concentrates, Silver City 1° × 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183–J, scale 1:500,000.

______ 1986, Geochemical maps of barium in stream-sediment concentrates, Silver City 1° × 2° quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF–1183–K, scale 1:500,000.