UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Occurrence of Tungsten in the Sangre de Cristo Range Near Santa Fe, New Mexico: Possible Stratabound Scheelite Peripheral to Favorable Settings for Volcanogenic Massive-Sulfide Deposits

By

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

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Illustrations

Introduction

In May of 1979 a mineral survey by the U.S. Geological Survey was begun in the proposed RARE II additions to the Pecos Wilderness, and was continued during May and early June 1980. This work, done in compliance with the Wilderness Act, was an extension of a previous mineral survey of the existing Wilderness and some adjacent areas. The previous work was done mainly in 1977, and the results are now available (U.S. Geological Survey, U.S. Bureau of Mines, and New Mexico Bureau of Mines and Mineral Resources, 1980). By far the largest of the RARE II additions is in the area shown on figure 1, which centers about 12 km east of Santa Fe and is called the Glorieta Baldy area in this report. This report describes the occurrence of tungsten in relation to several other elements that were detected spectrographically in panned concentrates of heavy minerals obtained from stream sediments. We believe that our study illustrates the great power of the gold pan as an exploration tool, particularly when used in close conjunction with careful geologic mapping in a complex metamorphic terrane. This work has revealed the presence of highly anomalous amounts of tungsten in the study area, in a setting that strongly suggests a stratabound setting in the Precambrian rocks, in a peripheral relationship to likely hosts for volcanogenic massive-sulfide deposits.

Geologic setting

As shown previously (Miller and others, 1963; Moench and Robertson, 1980) the Precambrian of the Sangre de Cristo Range from the Truchas Peaks area south to the northern border of the area of figure 1 divides into (1) an eastern terrane of folded metasedimentary and metavolcanic rocks, variably metamorphosed from low to high ranks and intruded by pink granite, and (2) a western batholithic terrane of medium-grained granite to tonalite with extensive screens and roof pendants of sillimanite-zone schist, gneiss, and migmatite. These two terranes are separated by the Pecos-Picuris fault, now known to extend south at least to the vicinity of Glorieta, New Mexico. The eastern terrane subdivides into a package of quartzite and aluminous schist on the north, and, on the south, a complex younger assemblage of intertonguing and intergrading metavolcanic and richly volcaniclastic metasedimentary rocks, together with an inferred subvolcanic complex of metadiabase, quartz diorite, tonalite, and trondhjemite. Robertson and Moench (1979) call this younger assemblage the Pecos greenstone belt. Metavolcanic rocks of the belt are host to the massive-sulfide deposit at the Pecos mine, recently interpreted as a stratabound volcanogenic deposit (Riesmeyer, 1978; Giles, 1976). On figure 1 of a report by the U.S. Geological Survey, U.S. Bureau of Mines, and New Mexico Bureau of Mines and Mineral Resources (1980), a high potential for deposits of this type is shown in a large area immediately east of the Pecos-Picuris fault that includes the Pecos mine and the Macho Canyon area of figure 1 of this report. No potential was suspected anywhere west of the fault, because that area was thought to be underlain by rocks of the batholithic terrane in a tract extending nearly from the town of Truchas south to U.S. Interstate Highway 25 south of Santa Fe (see Robertson and Moench, 1979, fig. 1).

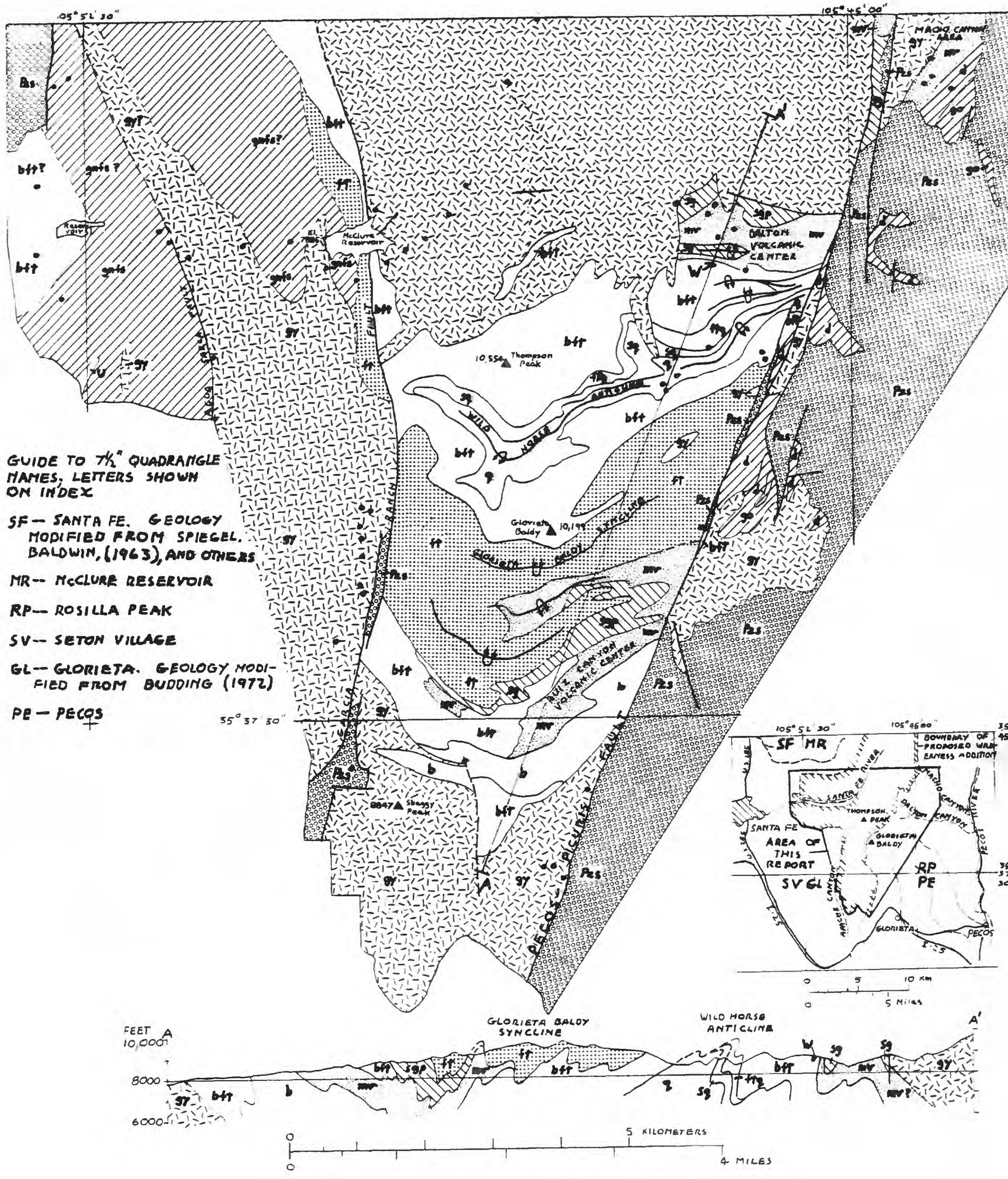

Figure 1.--Geologic map and section of the Glorieta Baldy area, Santa Fe County, New Mexico, showing sites of geochemical samples. Mapped and sampled in May 1979, by Robert H. Moench and Sarah K. Odland, assisted by Karin Budding and Gail Wadsworth, and in 1980 by Moench, assisted by Jill L. Schneider.

EXPLANATION

Pzs UPPER PALEOZOIC SEDIMENTARY ROCKS--Sangre de Cristo, Madera, Sandia, and Espiritu Santo Formations

PRECAMBRIAN PLUTONIC ROCKS

gyl Younger granite (probably about 1.65 b.y. old)--Pink massive to foliated two-mica granite; near contact north of Thompson Peak, coarse-grained granite of main body grades to aphanite and quartz porphyry

go Older granitic rocks of inferred subvolcanic complex (probably 1.7 to 1.75 b.y. old)--White to pale-brownish conspicuously foliated quartz diorite, tonalite, trondhjemite, and granodiorite

d Mafic rocks of inferred subvolcanic complex--Dark massive to foliated intrusive amphibolite and gabbro; commonly mixed with silicic rocks of the inferred complex

u Ultramafic amphibole--chlorite schist at the western border of the mapped area

gnfs Undivided felsic gneiss and stratified rocks--Medium- to fine-grained light-colored granitic rocks; has polydeformed foliation and is possibly related to unit go; subordinate amphibolite, aphanitic-bedded felsic metatuff, and pelitic schist

PRECAMBRIAN STRATIFIED ROCKS (probably 1.7 to 1.75 b.y. old)

ft Felsic metatuff--Includes thinly bedded to massive, aphanitic pale-orange quartz-feldspar granofels, locally epidotic, and spectacularly crossbedded, coarser grained light-colored muscovite-quartz-feldspar schist interbedded with subordinate quartzite

sg, **sgp** Metashale and metagraywacke--Metashale is two-mica schist, commonly rusty weathering; locally contains garnet, staurolite, or sillimanite, in accord with metamorphic rank. Metagraywacke is dark aphanitic biotite-quartz-plagioclast granofels. Probable pyroclastic mudflow deposits (sgp), having clasts of felsite as large as 5 cm across scattered through a matrix of pelitic schist

mv Mixed felsic and mafic metavolcanic rocks and associated volcano-clastic metasedimentary rocks, hydrothermally altered rocks, and local iron-formation; pyroclastic metarhyolite abundant in the Dalton volcanic center, some containing clasts of boulder size

bft Metabasalt and felsic metatuff--Interstratified in variable proportions. The metabasalt is dark amphibolite or greenstone, locally displaying amygdales, pyroclastic features, and pillows. The felsic metatuff is thinly bedded pale-orange aphanitic quartz-feldspar granofels, some epidotic

b Mainly metabasalt

ftq Interbedded felsic metatuff and quartzite

sq Interbedded metashale and quartzite--The metashale is aluminous two-mica schist. The quartzite occurs as thin beds, some graded or cross-laminated or thinly parallel laminated

q Quartzite and local quartz metaconglomerate--Interbedded with minor pelitic two-mica schist; thinly or thickly bedded, commonly crossbedded, locally graded

MAP SYMBOLS

CONTACT--Dashed where approximately located or conjectural

FAULT--Dashed where approximately located or conjectural; horizontally mullioned mylonite exposed along the Pecos-Picuris fault, which truncates the Wild Horse anticline

OVERTURNED SYNCLINE

OVERTURNED ANTICLINE

W TUNGSTEN LOCALITY--Float of coarsely crystallized scheelite-bearing epidote-amphibole rock associated with metabasalt

SITE OF GEOCHEMICAL SAMPLE

The assumption of an exclusively granitic terrane west of the Pecos-Picuris fault proved erroneous in 1979 when it was discovered that much of the Glorieta Baldy area is underlain by folded metasedimentary and metavolcanic rock of low to high metamorphic rank, intruded, as are similar rocks exposed east of the fault, by pink granite. Further mapping revealed a succession of rocks impressively similar in character and stratigraphic order to the stratified rocks of the quartzite-schist package and the metavolcanic assemblage exposed east of the Pecos-Picuris fault. The results of the new mapping are shown on figure 1. General character of the rock units is indicated in the map explanation.

As shown, compositionally mature quartzite and aluminous schist are stratigraphically lowest in the succession (units q and sq); they define the axial belt of the Wild Horse anticline--a tight, north-overturned, complexly redeformed fold that is truncated on the east by the Pecos-Picuris fault. The anticline is named for its expression in Wild Horse Canyon. On the limbs of the anticline the quartzite-rich sequence is overlain by an extensive sequence of interstratified metabasalt and pale-orange fine-grained bedded felsic metatuff (unit bft). At most places the contact between the two sequences appears to be conformable and abrupt, but on part of the north limb of the anticline it is gradational through a unit (ftq) of interbedded quartzite and felsic metatuff. Locally, areas composed almost entirely of metabasalt (unit b) can be separated from unit bft. Exposed in two areas of the Glorieta Baldy area are complexly mixed volcanic assemblages (unit mv) that contain abundant metarhyolite, probably erupted from nearby volcanic centers. Of the two inferred volcanic centers named on figure 1, the Dalton center contains the most abundant and most coarsely pyroclastic metarhyolite. At the highest exposed stratigraphic level in the volcanic succession is a thick and extensive layer of felsic metatuff (unit ft), some displaying spectacular crossbedding. These rocks are exposed along the axial belts of the Glorieta Baldy syncline, and the unnamed syncline to the south.

Exposed immediately east of the Pecos-Picuris fault, and beneath the upturned and faulted upper Paleozoic sedimentary beds, are abundant metadiabase and gabbro (unit d), associated light-colored granitic rocks (unit go), and younger pink granite (unit gy). Units "d" and "go" are part of the inferred subvolcanic complex of Moench and Robertson (1980) and Robertson and Moench (1979). The complex extends north to the Macho Canyon area where it appears to lie below mixed metavolcanics of the same mass that is host to the Pecos massive-sulfide deposit.

Although mapping has not been completed west of the Garcia Ranch fault, small areas underlain by felsic metatuff (ft) and interstratified felsic metatuff and metabasalt (bft), indicate that rocks of the Glorieta Baldy fault block extend west of the Garcia Ranch fault. The undivided felsic gneiss and stratified rocks (unit gnfs) undoubtedly contains abundant metavolcanics, probably mainly of units "ft" and "bft." It is composed mainly of conspicuously foliated granitic rocks, however, some of which are certainly plutonic and probably related to the subvolcanic complex. In outcrops the plutonic rocks and the stratified felsic metatuffs commonly are interlayered, difficult to distinguish, and not easy to map separately.

Metamorphic grade in the Glorieta Baldy area increases westward from the biotite and garnet zones near the Dalton volcanic center and from the staurolite zone near the eastern part of the Ruiz volcanic center. Although rocks having appropriate compositions to yield aluminum silicate minerals are not abundant, rocks of the mountainous central axis of the area seem to be sillimanite-zone schist and gneiss, locally migmatitic and abundantly intruded by pegmatite. The high rank character of the stratified rocks continues west across the Garcia Ranch fault to the western border of the mapped area. The stratified rocks of the Glorieta Baldy area were deformed at least twice. The early deformation produced the major east-trending folds and axial surface schistosity, most conspicuous in the pelitic schist and in the coarse muscovitic crossbedded felsic tuff. The later deformation(s) warped the east-trending folds about north-trending axial surfaces that are roughly parallel to the Pecos-Picuris and Garcia Ranch faults.

Geochemical investigation

In the course of geologic mapping by foot traverses in 1979, 46 concentrates of heavy minerals were collected by panning sediments from stream tributaries that drain the part of the Glorieta Baldy area proposed for inclusion in the Pecos Wilderness. Four additional samples were obtained during the main effort in 1977, and three more samples were collected in 1980 (fig. 1A). Each sample was prepared as follows for spectrographic analysis: After drying, the light minerals (mainly quartz and feldspar) were removed by flotation in bromoform and discarded. Magnetite was removed from the heavy fraction using a hand magnet. The nonmagnetic fraction was then run through a Franz isodynamic magnetic separator[1/] at 0.2 amperes (side tilt 15°, forward tilt 25°) to remove all the remaining magnetite, ilmenite, and pyrrhotite. The nonmagnetic fraction was then rerun at 0.5 amperes, and the magnetic fraction was stored for possible further analysis. The nonmagnetic fraction was rerun at 1 ampere, and divided into nonmagnetic and magnetic fractions. Except for the 0.5 amp magnetic fractions of samples collected in 1980, all three fractions were analyzed by Erickson for 31 elements by semiquantitative spectrographic analysis. This work provided the mainstay of the geochemical survey.

In addition to this work, samples of bulk sediment were collected from 43 of the same sites. After drying and sieving, the -80-mesh fractions were analyzed spectrographically by Erickson, and determinations were made by John G. Viets (USGS) of cold acid-extractable copper and citrate-soluble total heavy metals.

The important results of this work are shown on figures 2 through 10. On all these figures the geology is generalized from figure 1, as shown on figure 1A. These and other data are being incorporated into a report on the entire area of the Pecos Wilderness, RARE II additions, and adjacent areas.

[1/] The use of trade names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

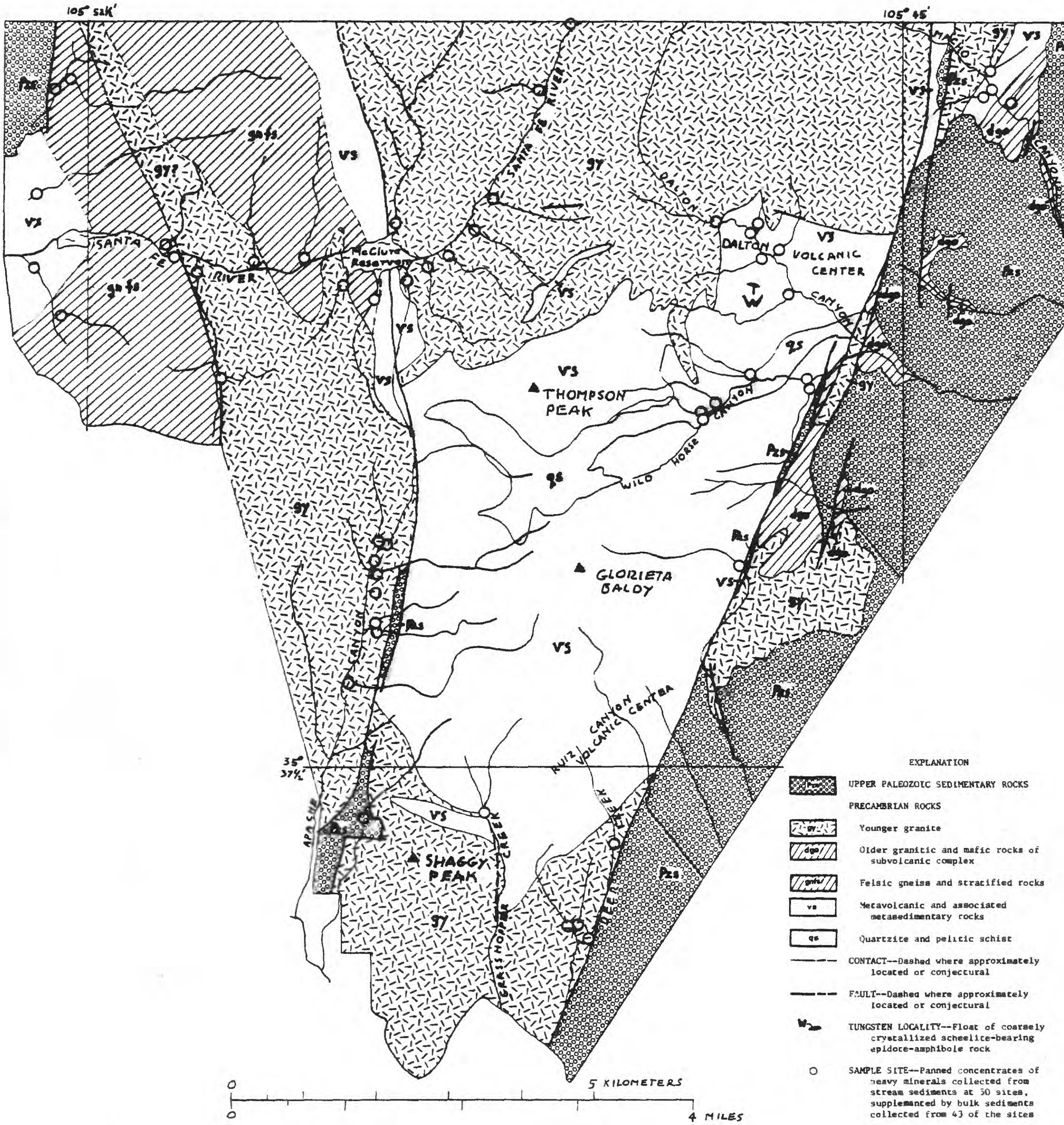

Figure 1A. Simplified geologic map of the Glorieta Baldy area showing sites of geochemical samples (circles). Geology simplified from figure 1.

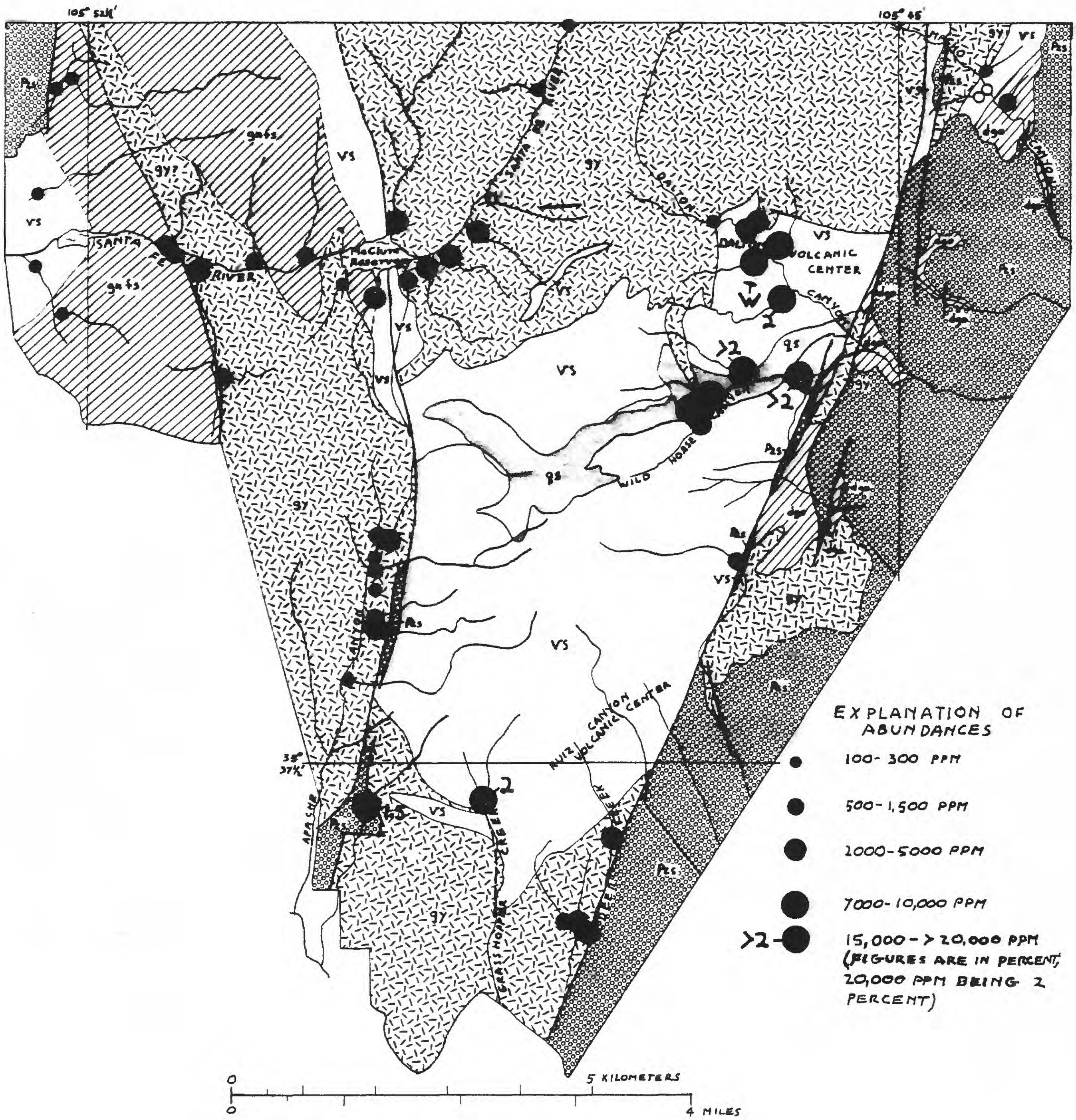

Figure 2.--Geochemical map showing tungsten in heavy-mineral concentrates from stream sediments; nonmagnetic fractions at 1 amp. Data in parts per million; minimum detection limit is 100 ppm W.

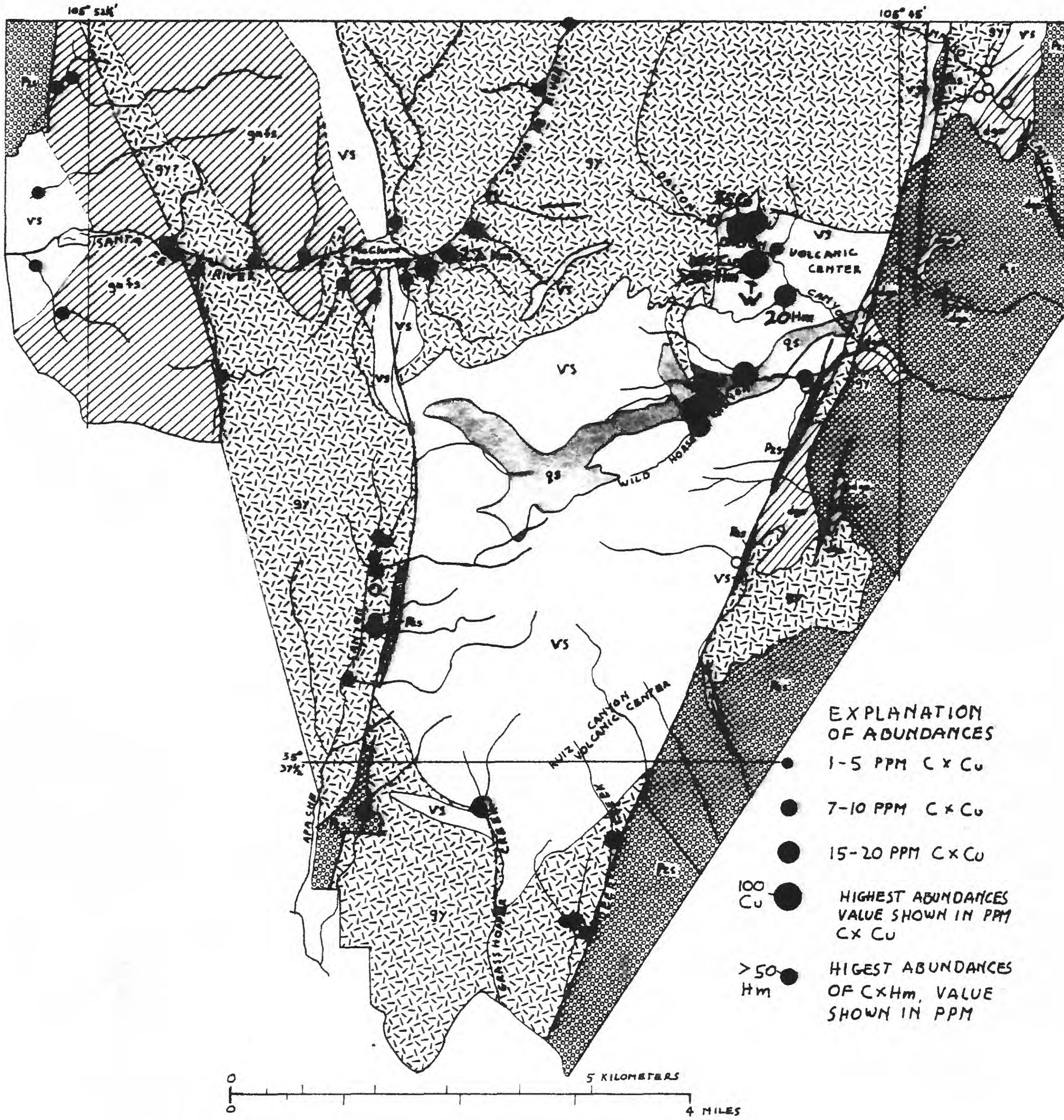

Figure 3.--Geochemical map showing cold acid-extractable copper (CxCu) and citrate-soluble heavy metals (CxHm) in -80-mesh sediments collected from streams. Data in parts per million; analyses by J. G. Viets.

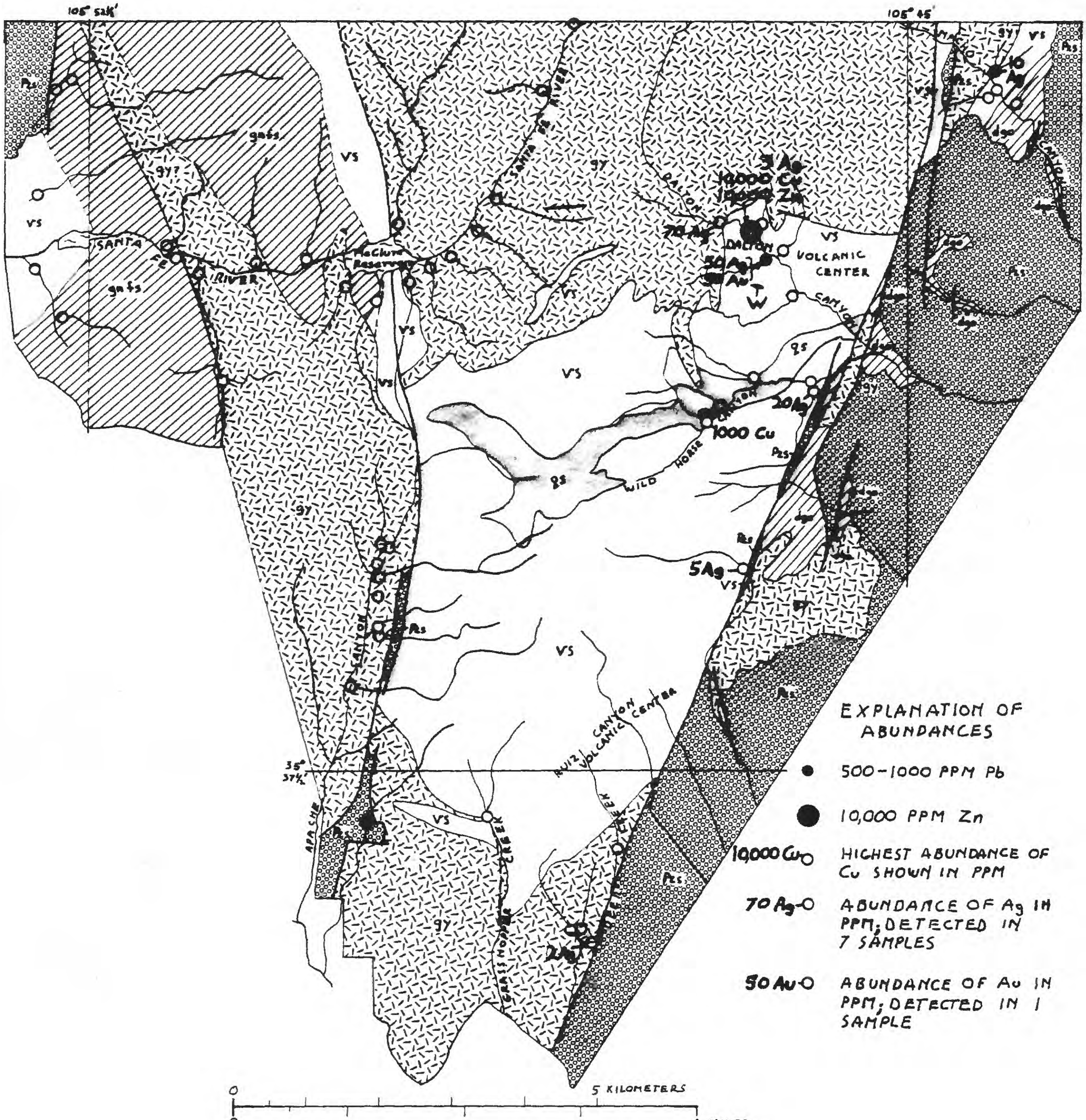

Figure 4.--Geochemical map showing gold, silver, and high abundances of copper, lead, and zinc in heavy-mineral concentrates from stream sediments; Au, Ag, Zn, and Pb data from nonmagnetic fractions at 1 amp, Cu data from magnetic fractions at 1 amp. Data in parts per million; mimimum detection limits are 20 ppm Au, 1 ppm Ag, 10 ppm Cu, 500 ppm Zn, and 20 ppm Pb.

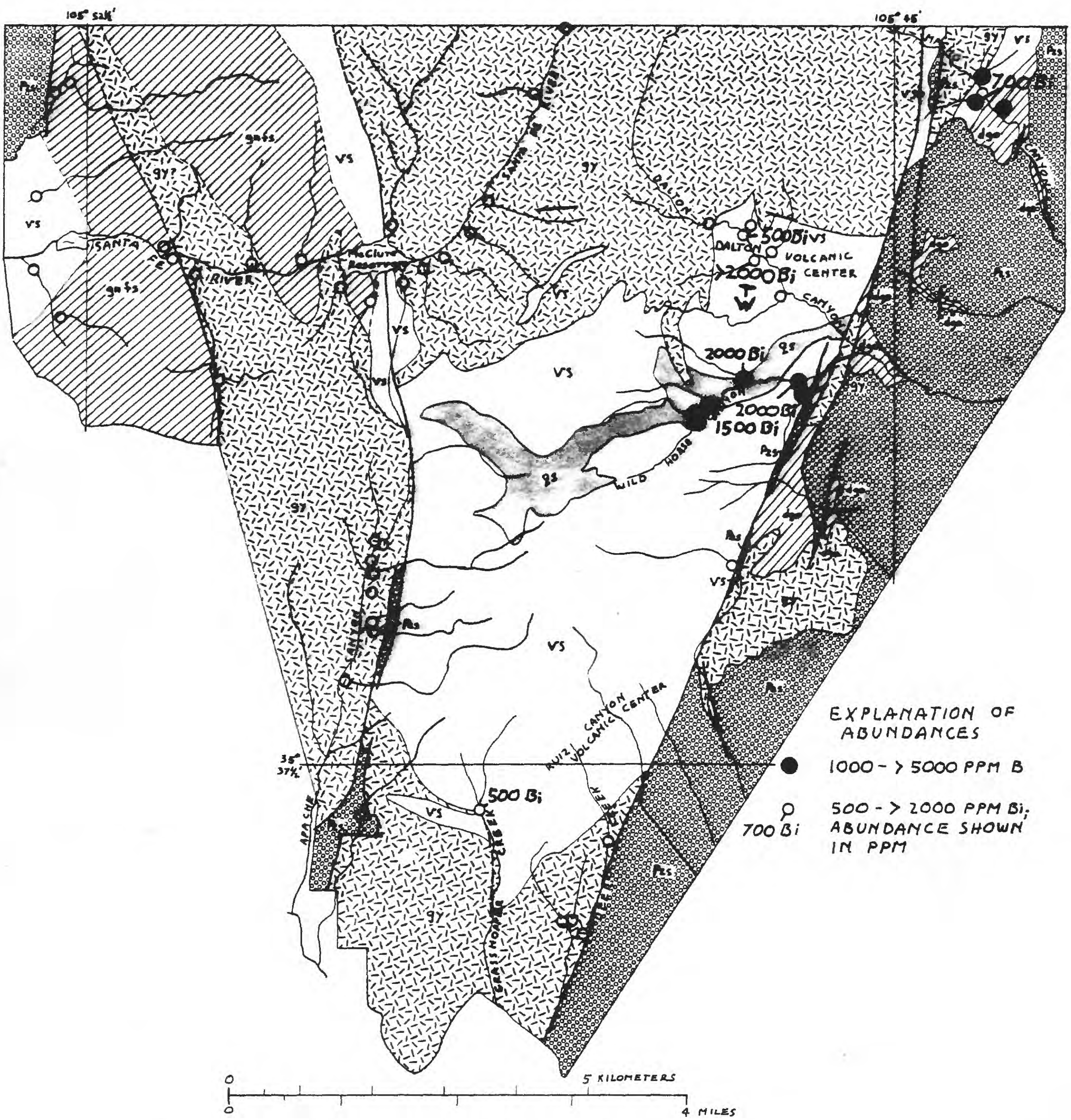

Figure 5.--Geochemical map showing bismuth and boron in heavy-mineral concentrates from stream sediments; Bi data from nonmagnetic fractions at 1 amp, B data from magnetic fractions at 1 amp. Data in parts per million; minimum detection limits are 20 ppm for Bi and B.

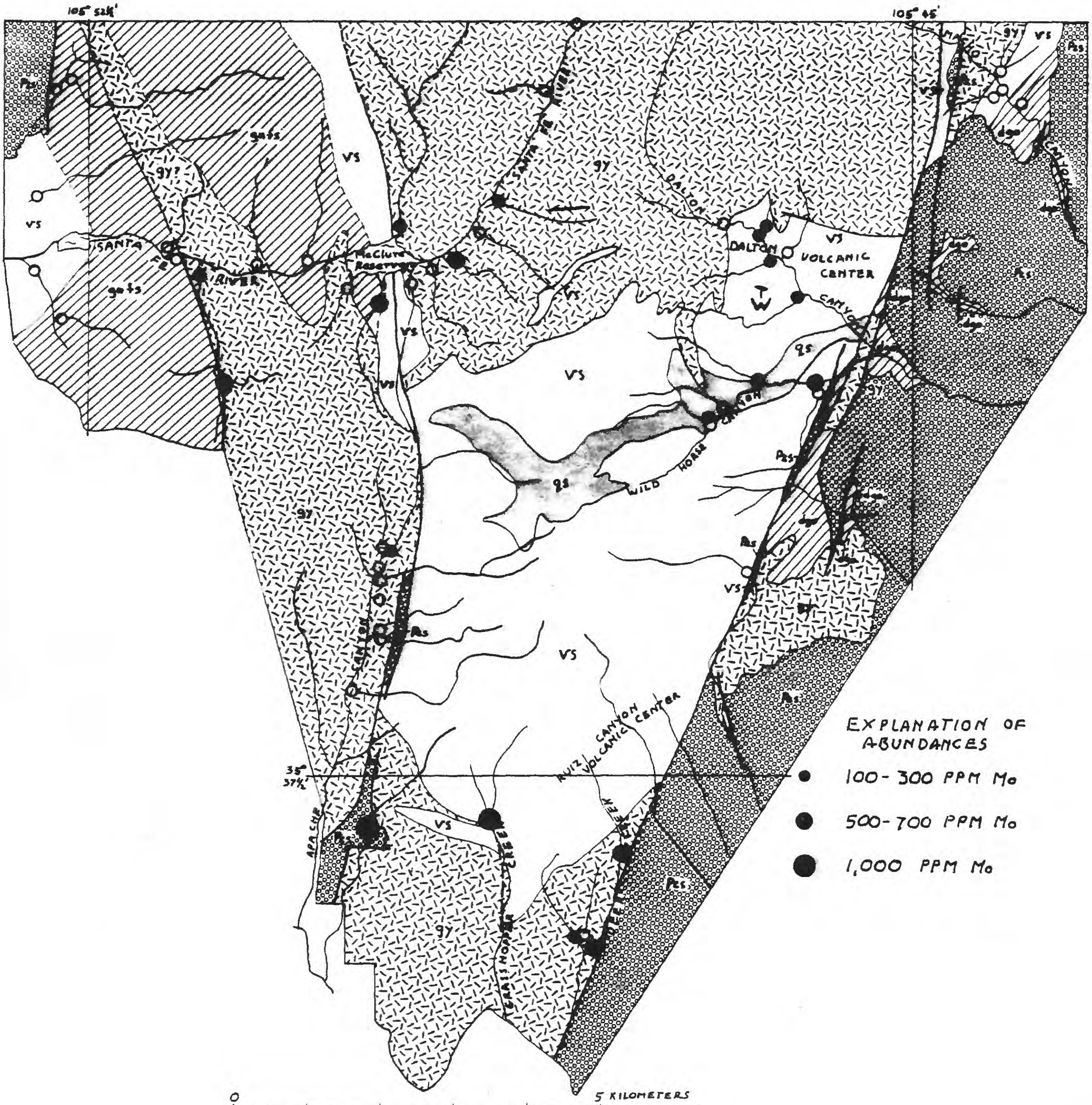

Figure 6.--Geochemical map showing molybdenum in heavy-mineral concentrates from stream sediments; nonmagnetic fractions at 1 amp. Data in parts per million; minimum detection limit is 10 ppm Mo.

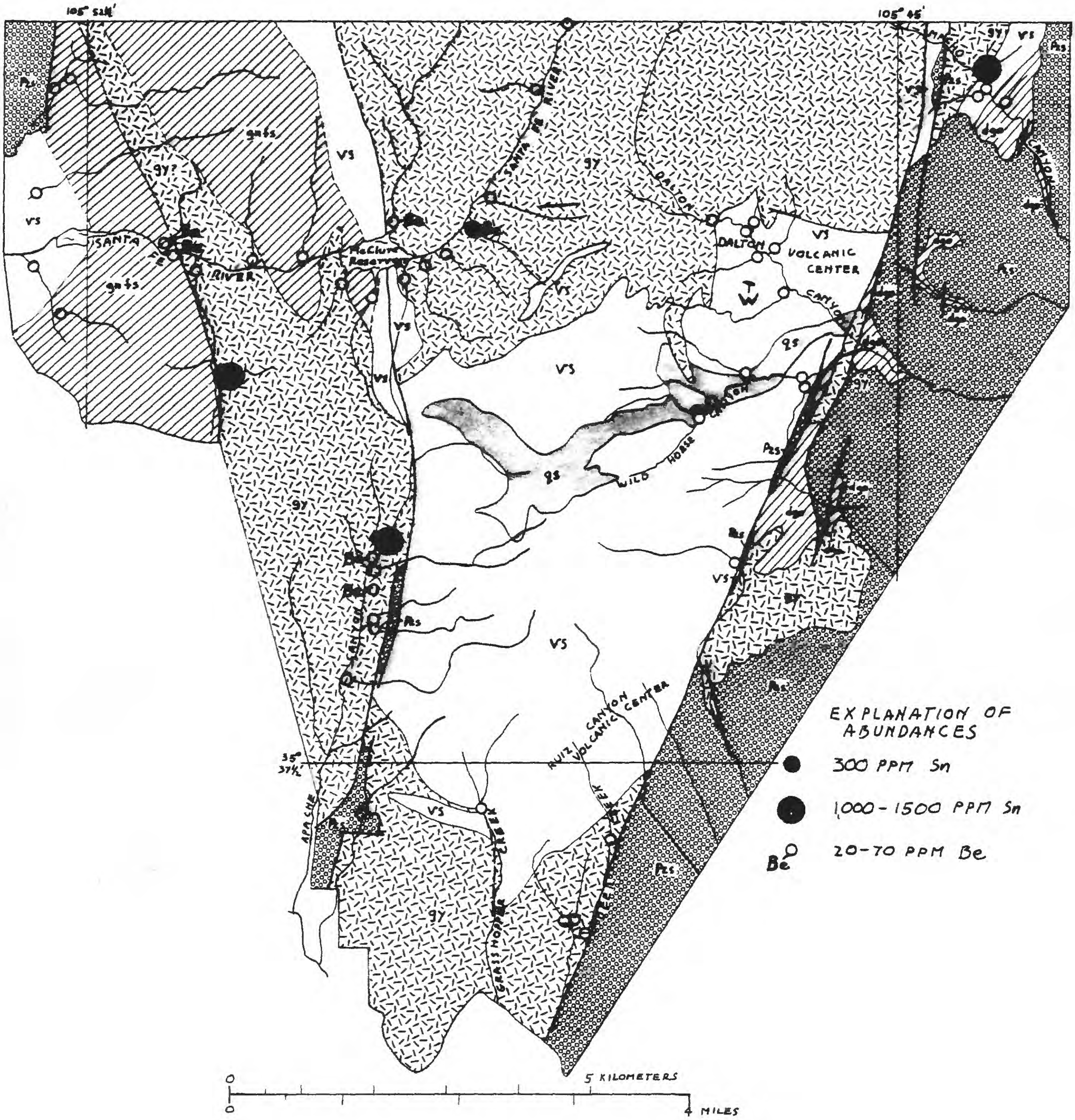

Figure 7.--Geochemical map showing tin and beryllium in heavy-mineral concentrates from stream sediments; data for Sn for magnetic and nonmagnetic fractions at 1 amp and magnetic fractions at 0.5 amp; data for Be from nonmagnetic fractions at 1 amp and magnetic fractions at 0.5 amp. Data in parts per million; minimum detection limits are 20 ppm Sn, and 2 ppm Be.

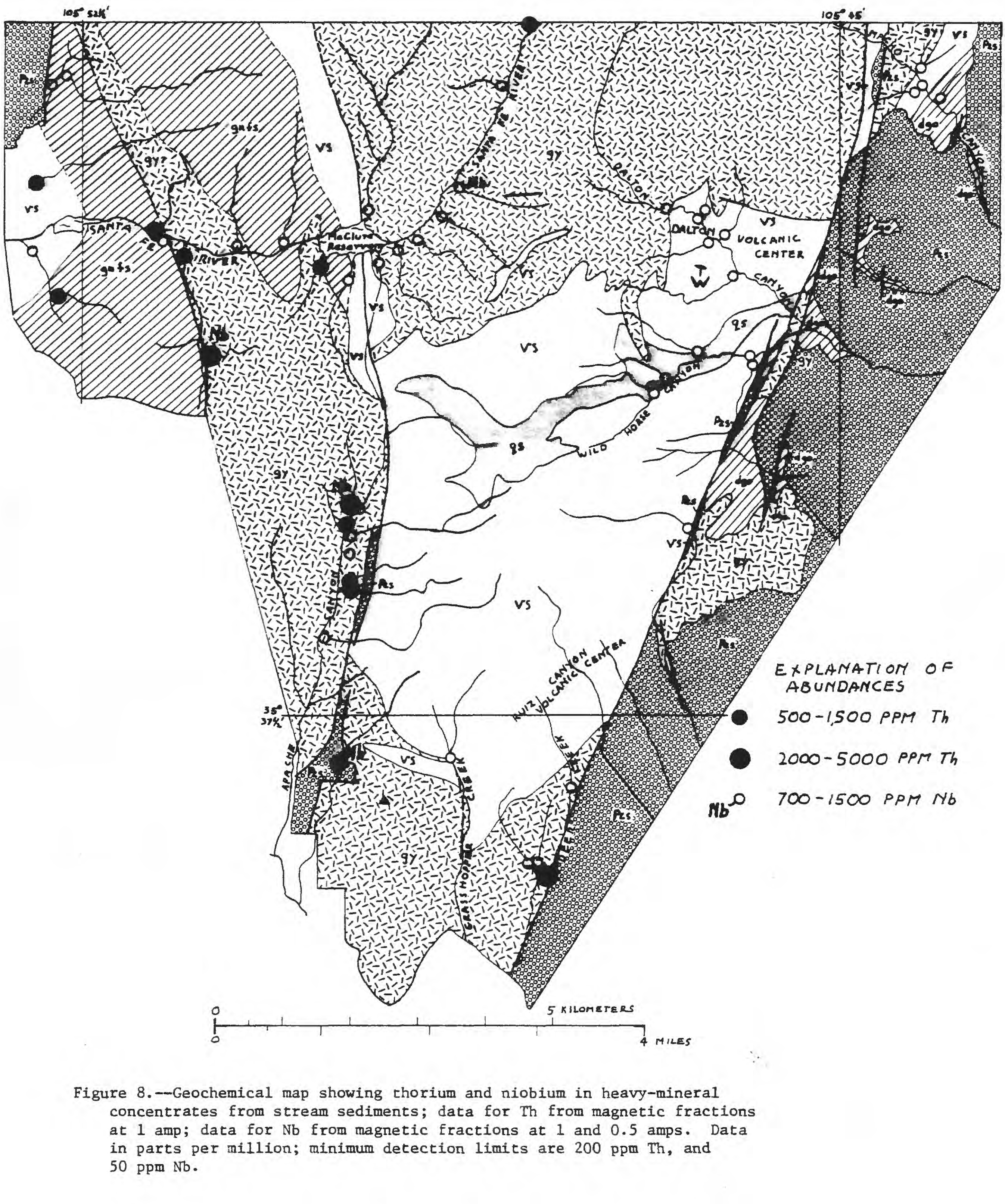

Figure 8.--Geochemical map showing thorium and niobium in heavy-mineral concentrates from stream sediments; data for Th from magnetic fractions at 1 amp; data for Nb from magnetic fractions at 1 and 0.5 amps. Data in parts per million; minimum detection limits are 200 ppm Th, and 50 ppm Nb.

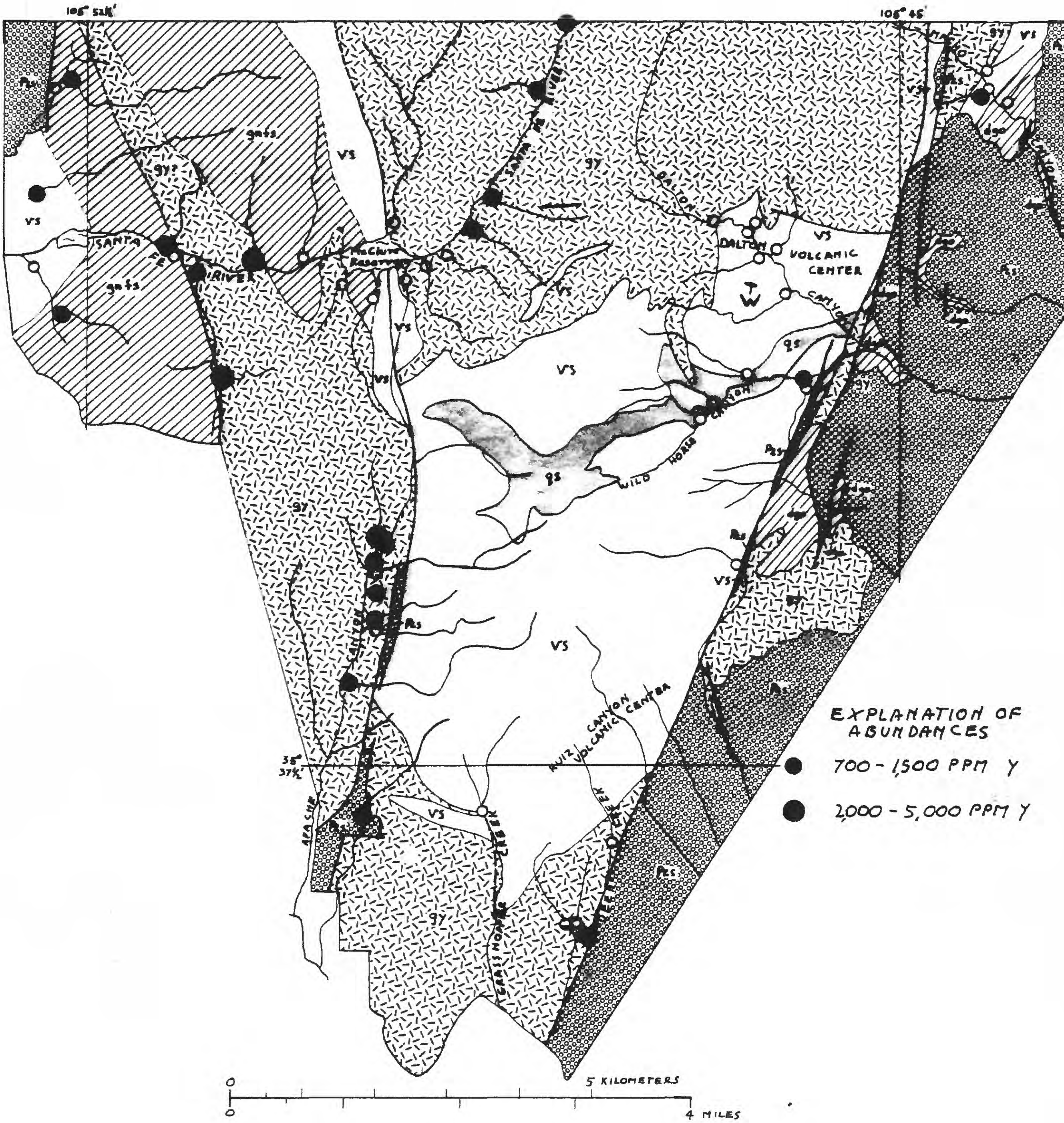

Figure 9.--Geochemical map showing yttrium in heavy-mineral concentrates from stream sediments; data from magnetic fractions at 1 amp. Data in parts per million; minimum detection limit is 20 ppm Y.

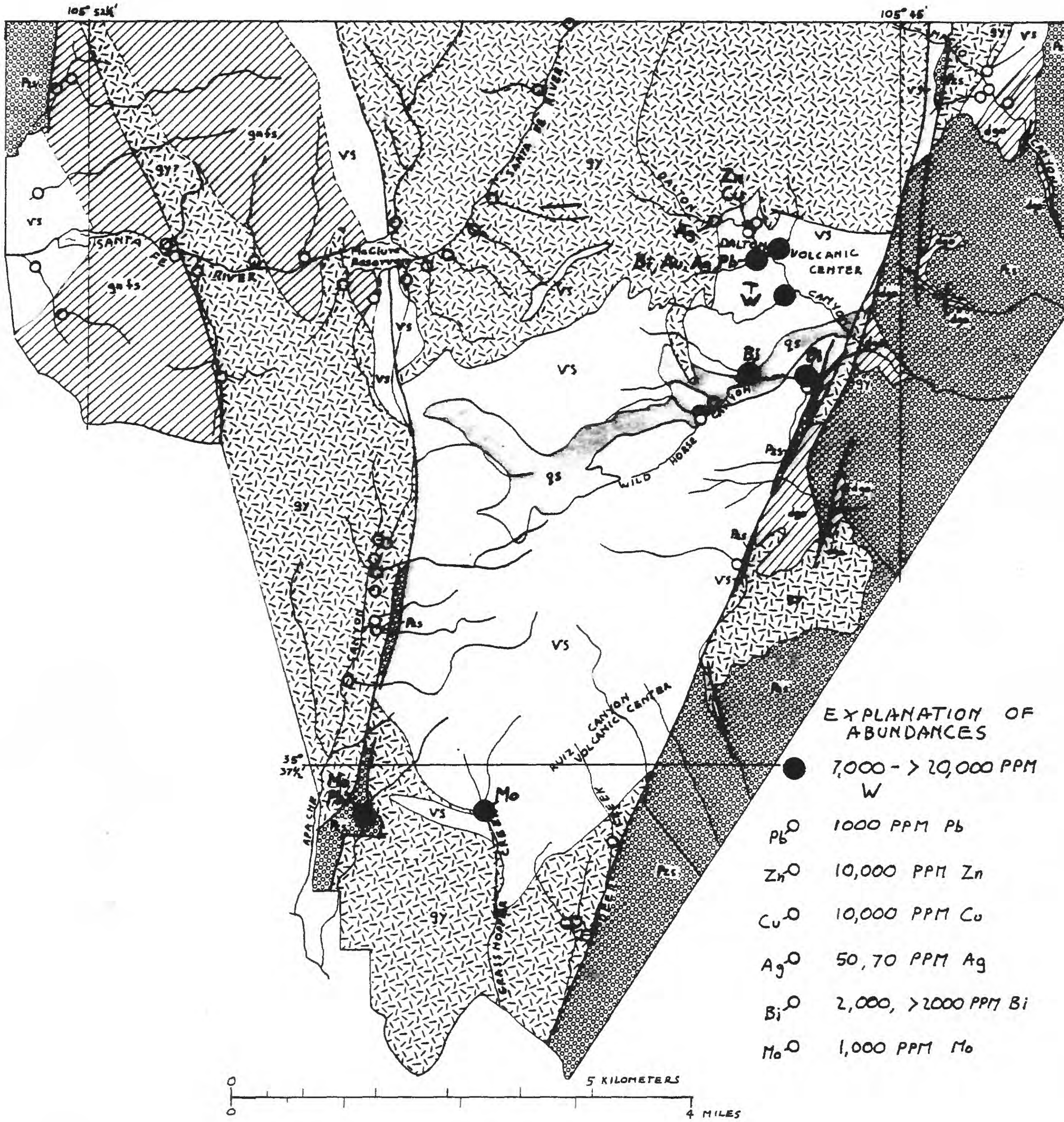

Figure 10. Summary geochemical map showing greatest abundance of tungsten, base and precious metals, bismuth, and molybdenum in heavy mineral concentrates from stream sediments.

Geochemical associations

Figures 2 and 4 through 10 show that the abundances of elements in the heavy-mineral concentrates divide into two broad associations. The greatest abundances of tungsten, base and precious metals, bismuth, boron, and molybdenum are associated with the stratified rocks of the Glorieta Baldy Block, between the Garcia Ranch and Pecos-Picuris faults (figs. 2, 4, 5, and 6). In contrast, the greatest abundances of tin, beryllium, thorium, niobium, and yttrium are found in concentrates from streams that drain areas underlain largely (at some sites entirely) by two-mica granite (figs. 7, 8, and 9). These latter elements are thus clearly of granitic association. Although the tin-rich sample from a tributary to Macho Canyon in the northeast was previously suspected to have a volcanogenic association (Moench and others, 1980), a granitic association now seems most likely. The Macho Canyon tin-rich sample drainage area is underlain by granite and by mixed metavolcanic rocks (fig. 7). Elsewhere the greatest abundances of tin are outside the metavolcanic terrane.

The summary geochemical map (fig. 10) excludes the elements of clearly granitic association, in order to emphasize the metavolcanic association of the other elements. The greatest abundances of the elements shown on figure 10 either are within the areas of mixed metavolcanic rocks, or they are peripheral to those areas. The association with the Dalton volcanic center is particularly impressive. the Dalton area has the rock associations--proximal silicic volcanics, both coarse pyroclastics and flows or domes, and apparently hydrothermally altered rocks (now metamorphosed)--that are the hallmark of the now-classic setting of 60 percent or so of productive massive-sulfide deposits in Precambrian and Paleozoic greenstone belts elsewhere in the world. The Glorieta Baldy area clearly contains a major extension of the Pecos greenstone belt of Robertson and Moench (1979).

Spectrographic analyses of the heavy-mineral concentrates show clear evidence that base and precious metals are greatly concentrated in the area of the Dalton center (fig. 4). This association is confirmed by the data on cold acid-extractable copper and citrates-soluble total heavy metals obtained from the bulk samples of stream sediments (fig. 3). It is noteworthy that if we had relied entirely upon bulk samples, evidence of important base- and precious-metals sulfide mineralization in the Dalton center would have been detected, but the tungsten would have been missed because its concentration in the bulk sediments is too low for detection by spectrographic analysis. This is true also for tin and some other elements.

Evidence of base- and precious-metals sulfide mineralization is most impressive in the Dalton center, but is not restricted to that area. The data for samples of bulk sediments indicate that the tributaries to Wild Horse Canyon are of second importance in this respect, followed by three tributaries to the Santa Fe River east of McClure Reservoir, then by the headwaters of Grasshopper Creek (fig. 3). The tributaries to the Santa Fe River drain the north slope of Thompson Mountain, and may cross sulfide-bearing metavolcanic rocks, either as inclusions in the younger granite or as country rock in the area south of the contact of the granite (fig. 3). Grasshopper Creek drains the western fringe of the Ruiz volcanic center. As shown on figure 4, copper, lead, and silver were detected in moderately high amounts in a few heavy-mineral concentrates outside the Dalton volcanic center. One concentrate was obtained from Dalton Creek upstream and west of the granite-metavolcanics contact, to determine if the evidence of mineralization farther downstream is restricted to the metavolcanics. Spectrographic analysis of the nonmagnetic fraction revealed a surprising 70 ppm silver, but only background amounts of copper, lead, and tungsten, and no zinc. Except for the silver, these data stand in contrast with the large amounts of copper and zinc that were detected in the heavy-mineral concentrate that was obtained only 0.5 km downsteam, within the area of the metavolcanics. Several small adits and prospect pits were found along that short segment of Dalton Creek, none exposing important amounts of sulfide minrals, but indicating the presence of commercial interest in the area. The silver could express a vein deposit in the granite, or sulfides in an inclusion of metavolcanic rock in the granite (Dalton Creek was traversed only 100 m or so upstream from the sample site, and again 2 km or so farther upstream), or it could express secondary leakage of silver through the granite from metavolcanic rocks that might be present at shallow depth.

Boron and bismuth in the heavy-mineral concentrates also are closely tied to the metavolcanic assemblage (fig. 5). The association of bismuth with the metavolcanics is in approximate accord with the previous findings in the Pecos Wilderness and adjacent areas (Moench and others, 1980, pl. 3A). Boron, probably all in tourmaline, was detected in greatest abundance in areas that appear to be peripheral to the most conspicuous volcanic centers. The Macho Canyon area, for example, may be considered to be peripheral to the center that is host to the Pecos deposit, and Wild Horse Canyon and its tributaries certainly drain areas underlain by rather distal metavolcanics relative to the Dalton center. In the course of mapping, the felsic tuffs exposed near the headwaters of Wild Horse Canyon and its tributaries were seen to contain abundant tourmaline. Tourmaline-bearing quartz veins also are exposed in the area. Although the boron might have been introduced during metamorphism or crystallization of the younger granite, the possibility that it is volcanogenic in origin should be kept in mind. John F. Slack (1980) has noted a convincing relationship between brown tourmaline (dravite) and stratabound massive-sulfide deposits of coastal Maine, whereas tourmaline of granitic origin of that area is black, iron-rich schorl. The possibility that a similar relationship exists in the Glorieta Baldy area deserves investigation.

Occurrence of tungsten

As shown by spectrographic analyses of the nonmagnetic fraction of heavy-mineral concentrates, tungsten is widely distributed in the Glorieta Baldy area (fig. 2) and in the previously studied Pecos Wilderness and adjacent areas (Moench and others, 1980; pl. 3B). In the previously studied area the greatest amounts that were detected are on the order of 500 to 1,500 ppm W--more than an order of magnitude smaller than the greatest amounts detected in the Glorieta Baldy area (fig. 2). Although the largest amounts of tungsten in the existing Wilderness were found in concentrates from streams that drain metavolcanics along at least parts of their lengths, a pegmatitic source for the tungsten was favored, and a stratabound distribution and volcanic origin were not considered. In the Glorieta Baldy area, abundances of 7,000 ppm to more than 20,000 ppm (2 percent) tungsten are found in heavy-mineral concentrates from the area of the Dalton volcanic center, in Wild Horse Canyon and its tributaries, and in two streams that drain the lower southern slope of Glorieta Baldy west of the Ruiz Canyon volcanic center (fig. 2). Because most of these same streams also drain areas that are underlain by granite or by quartzite and schist, the apparent association with the metavolcanics could be coincidental.

The sites of samples that yielded the greatest abundances of tungsten were resampled in 1980 and examined for scheelite, using an ultraviolet light. All were found to have at least a few grains of scheelite. Some of the samples from the sites showing 2 percent or more tungsten, show many grains, some of which are sharply angular particles the size of coarse sand.

No sources of tungsten were located in outcrop, but several fragments of scheelite-bearing float were found about 1/2 km west of Dalton Creek, where indicated on all the figures. The site is no more than about 50 m wide across strike (about east-west). It is at an elevation of about 8,960 feet on the gently sloping crest of the ridge between two small east-flowing tributaries to Dalton Creek. The float fragments could not have moved more than a few meters from their bedrock sources. Most of the bedrock and float in the immediate area of the scheelite-bearing fragments is fine-grained basaltic amphibolite, some weakly to strongly epidotic.

The scheelite is in coarsely crystallized unfoliated quartz-epidote-hornblende rocks. Five thin sections of the scheelite-bearing rock were cut. All show the same mineral assmblage. In all, rather ragged anhedral pale-green hornblende is intergrown with clean, well crystallized epidote, which in places is euhedral against quartz; the quartz forms irregular concentrations throughout the rock. The scheelite (optically positive, very high relief, low to moderate birefringence) is present in amounts that range from a trace to several percent. Individual grains are 1 mm to 5 mm across, anhedral but well crystallized; some are rather foggy and do not yield a good optic figure. The grains are disseminated throughout the rock, which also contains small amounts of sphene.

As shown on the geologic map (fig. 1) the site of the scheelite-bearing float is approximately 1/2 km east of the contact between metavolcanic rocks of the Dalton center and younger pink granite. As shown in section A-A′ of figure 1, the site is in the lower part of the metavolcanic succession, in an area where predominant metabasalt is interbedded with crossbedded and graded bedded felsic metatuff or tuffaceous metasandstone. As seen in outcrops in the side canyon to the south, some of the metabasalt appears to be pillowed, although tops were not determined. Tops were determined in the tuffaceous metasandstones, however; the beds face both north and south, indicating that the rocks are isoclinally folded. The beds that are closest to the rhyolite-bearing assemblage of unit mv, however, face north, in accord with the interpretation that the abundantly basaltic rocks and the site of the scheelite are stratigraphically below the richly rhyolitic rocks of unit mv. Sedimentary features of the tuffaceous metasandstones of the predominantly basaltic package suggest that these sediments are not locally derived. The basaltic flows, in contrast, may have come from nearby, for coarse basaltic agglomerate is exposed at least at one locality to the east in Dalton Canyon.

Interpretation

The distribution of the greatest abundances of tungsten and of base and precious metals in concentrates of heavy minerals, together with the geologic occurrence and character of the scheelite-bearing fragments of float (fig. 10), strongly suggest that scheelite in the Glorieta Baldy area is stratabound and volcanogenic in origin. This type of association has not been widely recognized on this continent. Some of the Precambrian scheelite occurrences in Colorado described by Tweto (1960) are in metamorphic rocks that have been recognized subsequently to be of volcanogenic origin, and Sheridan and Raymond (1977) reported scheelite in stratabound sulfide deposits in metamorphosed volcanogenic rocks in southern Colorado. In southern Europe the association of tungsten with thick successions of metavolcanic rocks has been known for many years. There, however, the association between tungsten, antimony, and mercury is emphasized (Maucher, 1976; Holl, 1977), bound to metasedimentary-metavolcanic rock assemblages, and probably in a facies relationship in which mercury and antimony, or antimony and tungsten, but not tungsten and mercury may occur together. Maucher (1976, p. 499-501) concludes that these elements are genetically related to basaltic volcanism and its silicic differentiates in the early Paleozoic Southern European province. Of the three important minerals of these elements--cinnabar, stibnite, and scheelite--scheelite is the most stable during metamorphism and moves the least.

To our knowledge the close association of scheelite with volcanogenic massive-sulfide deposits is not widely known. If the association is borne out by future studies in the Glorieta Baldy area, a large part of the Pecos greenstone belt and perhaps other Precambrian and Paleozoic volcanic belts that are well known for their massive-sulfide deposits should be re-examined in the same light for their tungsten potential.

The geochemical data on figure 10 show that the greatest measured abundance of molybdenum in heavy-mineral concentrates occur at two sites that also yielded 2 percent and 1.5 percent tungsten. Inasmuch as molybdenum proxies easily for tungsten in scheelite, the possibility exists that the molybdenum and tungsten are cogenetic. Further study is needed on the concentrates to find out if the molybdenum is in fact in the scheelite.

Acknowledgments

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References

Budding, A. J., 1972, Geologic map of the Glorieta quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 24.

Giles, D. L., 1976, Precambrian mineralization in the Southern Rocky Mountain region, in Woodward, L. A., and Northrop, S. A., eds., Tectonics and mineral resources of southwestern North America: New Mexico Geological Society Special Publication 6, p. 127-121.

Harmon, K. A., Crockett, J. H., and Shaw, D. M., 1975, Tungsten in iron formations: Geological Society of America Abstracts with Programs, v. 7, no. 6, p. 773.

Holl, R., 1977, Early Paleozoic ore deposits of the Sb-W-Hg formation in the Eastern Alps and their genetic interpretation, in Klemm, D. D., and Schneider, H. J., eds., Time and stratabound ore deposits: Springer-Verlag, p. 169-198.

Maucher, Albert, 1976, The stratabound cinnabar--stibnite-scheelite deposits, in Wolf, K. H. ed., Handbook of stratabound and stratiform ore deposits, v. 7, chapter 10: Amsterdam, Elsevier, p. 477-503.

Miller, J. P., Montgomery, Arthur, and Sutherland, P. K., 1963, Geology of part of the southern Sangre de Cristo Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 11, 106 p.

Moench, R. H., and Robertson, J. M., 1980, Geology of the Pecos Wilderness and adjacent areas, Santa Fe, San Miguel, Mora, Rio Arriba, and Taos Counties, New Mexico, Chapter A of U.S. Geological Survey, U.S. Bureau of Mines, and New Mexico Bureau of Mines and Mineral Resources, 1980, Mineral resources of the Pecos Wilderness and adjacent areas, Santa Fe, San Miguel, Mora, Rio Arriba, and Taos Counties, New Mexico: U.S. Geological Survey Open-File Report 80-382, p. 6-41.

Moench, R. H., Robertson, J. M., and Sutley, S. J., 1980, Geological, geochemical, and geophysical evaluation of the mineral resources of the Pecos Wilderness and adjacent areas, Santa Fe, San Miguel, Mora, Rio Arriba, and Taos Counties, New Mexico, Chapter B of U.S. Geological Survey, U.S. Bureau of Mines, and New Mexico Bureau of Mines and Mineral Resources, 1980, Mineral resources of the Pecos Wilderness and adjacent areas, Santa Fe, San Miguel, Mora, Rio Arriba, and Taos Counties, New Mexico: U.S. Geological Survey Open-File Report 80-382, p. 42-68.

Riesmeyer, W. D., 1978, Precambrian geology and ore deposits of the Pecos mining district, San Miguel, and Santa Fe Counties, New Mexico: Albuquerque, University of New Mexico M.S. thesis, 215 p.

Robertson, J. M., and Moench, R. H., 1979, The Pecos greenstone belt; A Proterozoic volcano-sedimentary sequence in the southern Sangre de Cristo Mountains, New Mexico: New Mexico Geological Society Guidebook, 30th Field Conference, Santa Fe Country, p. 165-123.

Sheridan, D. M., and Raymond, W. H., 1977, Preliminary data on some Precambrian deposits of zinc-copper-lead sulfides and zinc spinel (gahnite) in Colorado: U.S. Geological Survey Open-File Report 77-607, 27 p.

Slack, John F., 1980, Tourmaline--A prospecting guide for massive base-metal sulfide deposits in the Penobscot Bay area, Maine: Maine Geological Survey Special Economic Studies Series No. 8, 25 p.

Spiegel, Zane, and Baldwin, Brewster, 1963, Geology and water resources of the Santa Fe area, New Mexico, with contributions by F. E. Kottlowski and E. L. Barrows, and a section on geophysics by H. A. Winkler: U.S. Geological Survey Water-Supply Paper 1525, 258 p.

Tweto, Ogden, 1960, Scheelite in the Precambrian gneisses of Colorado: Economic Geology, v. 55, no. 7, p. 1406-1428.

U.S. Geological Survey, U.S. Bureau of Mines, and New Mexico Bureau of Mines and Mineral Resources, 1980, Mineral resources of the Pecos Wilderness and adjacent areas, Santa Fe, San Miguel, Mora, Rio Arriba, and Taos Counties, New Mexico: U.S. Geological Survey Open-File Report 80-382, 103 p.