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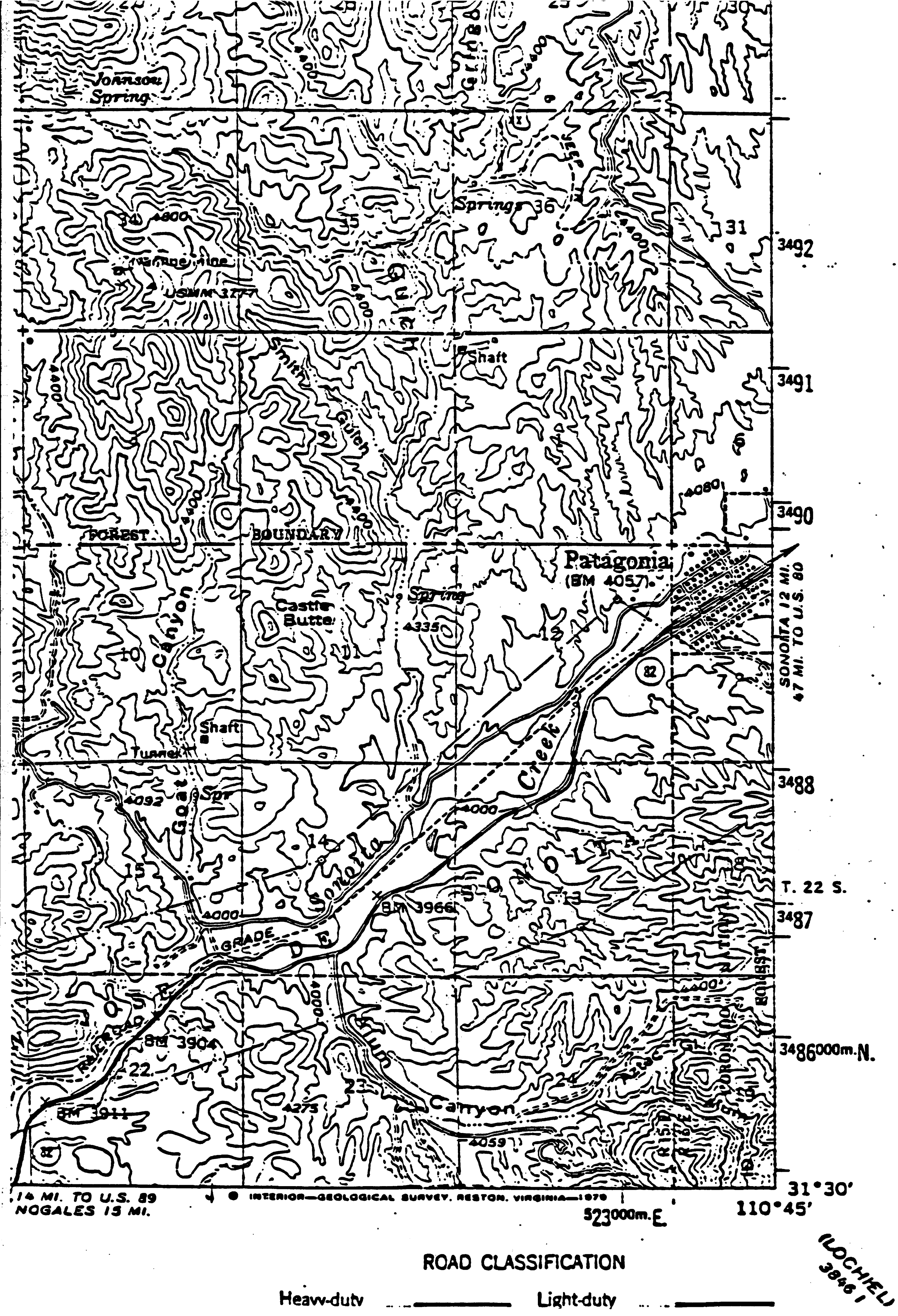
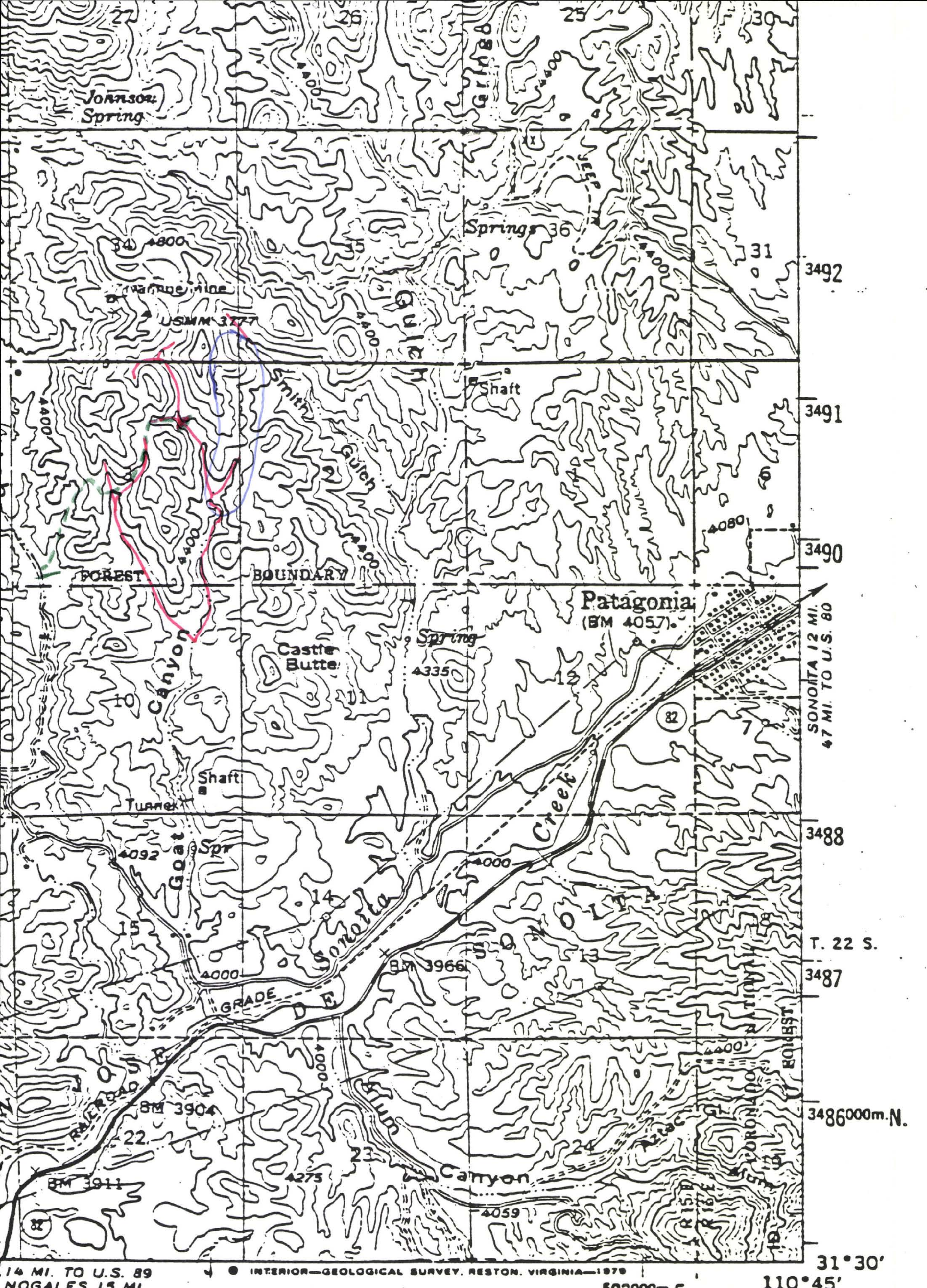


ROAD CLASSIFICATION

Heavy-duty ———— Light-duty ————



ROAD CLASSIFICATION

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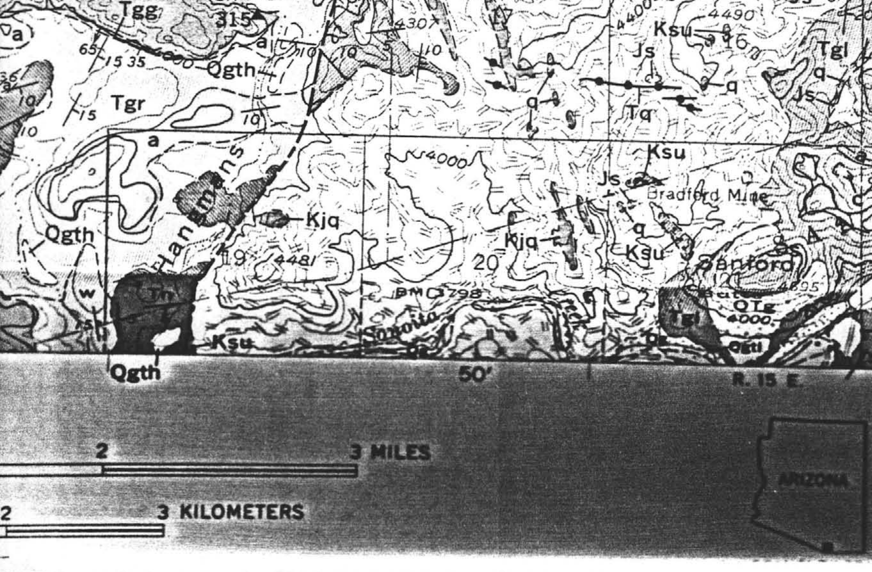
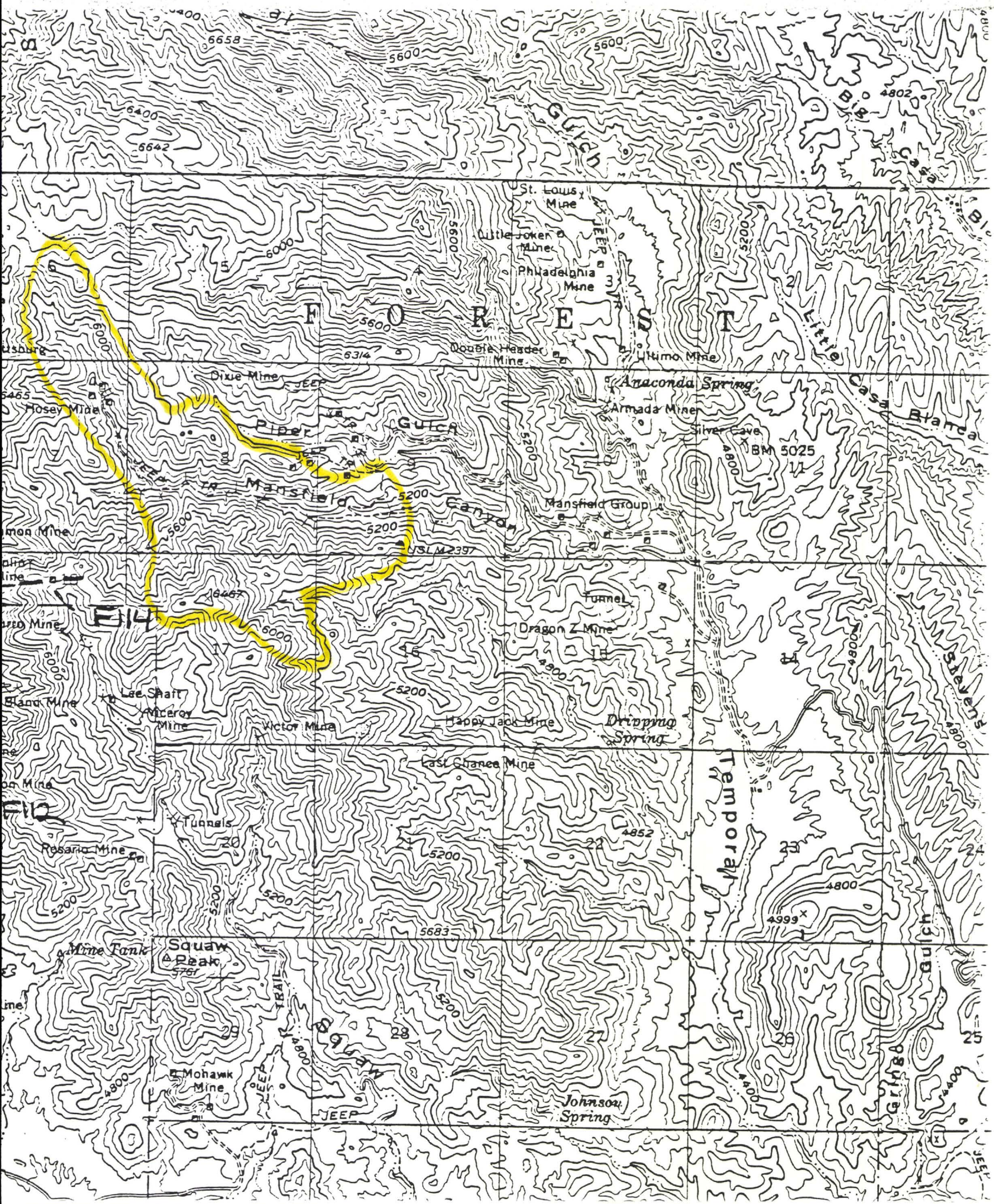


Geology by Harald Drewes, 1963–66,
assisted by G. C. Cone, Bruce Hansen, C
J. R. Riele and R. A. Rohrbacher



F O R E S T
Gulch
Big
Casa
Little Casa Blanca
St. Louis Mine
Little Joker Mine
Philadelphia Mine
Double Header Mine
Ultimo Mine
Anaconda Spring
Armada Mine
Silver Cave
BM 5025
Dixie Mine
Hosey Mine
Piper Gulch
Mansfield Canyon
Mansfield Group
JEEP TR.
Tunnel
Dragon Z Mine
Lee Shaft
Viceroy Mine
Victor Mine
Happy Jack Mine
Dripping Spring
Last Chance Mine
Temporal
Stevens
Tunnels
Rosario Mine
Mine Tank
Squaw Peak
5761
Mohawk Mine
TRAIL
JEEP
Johnson Spring
Gringo Gulch
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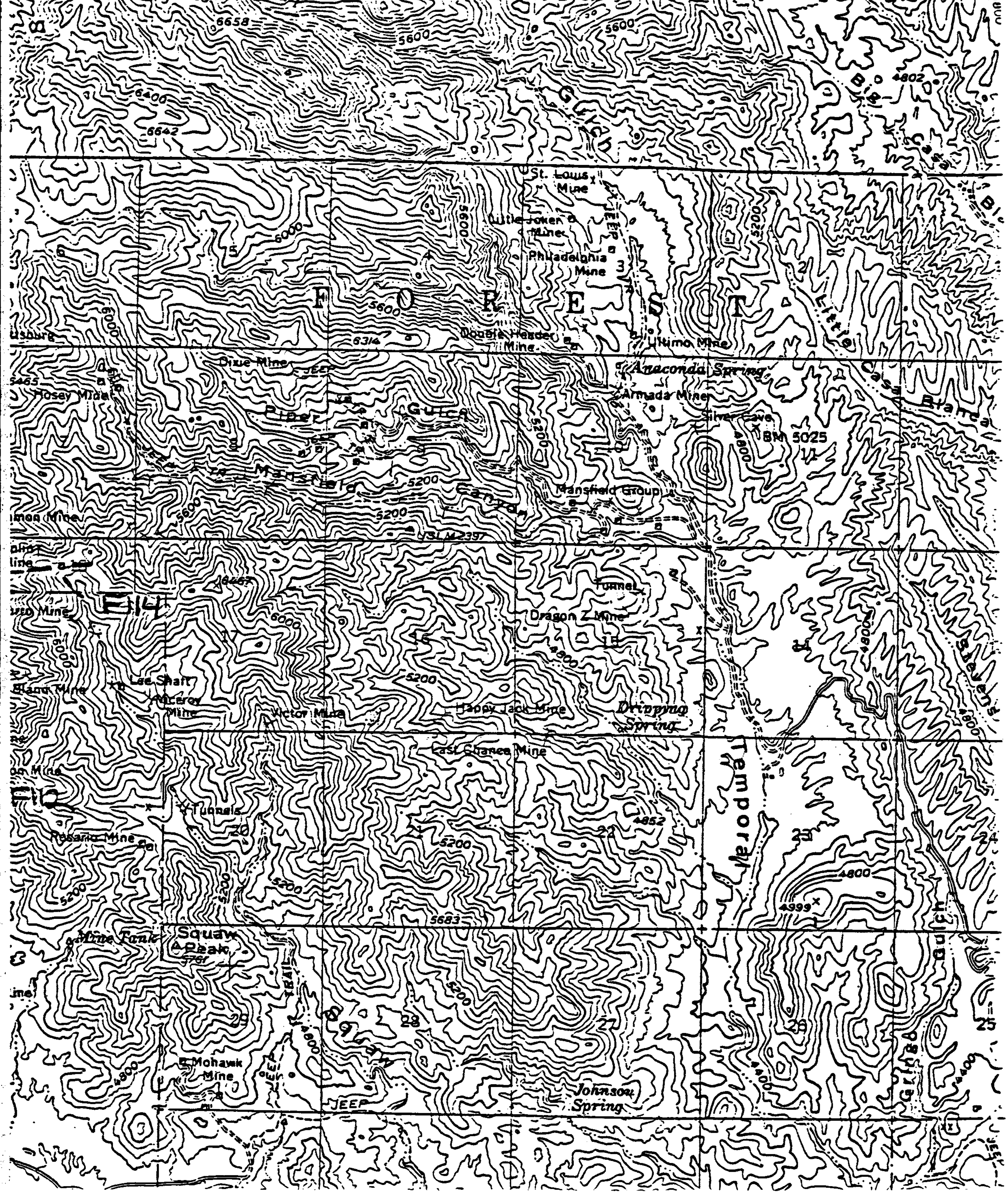

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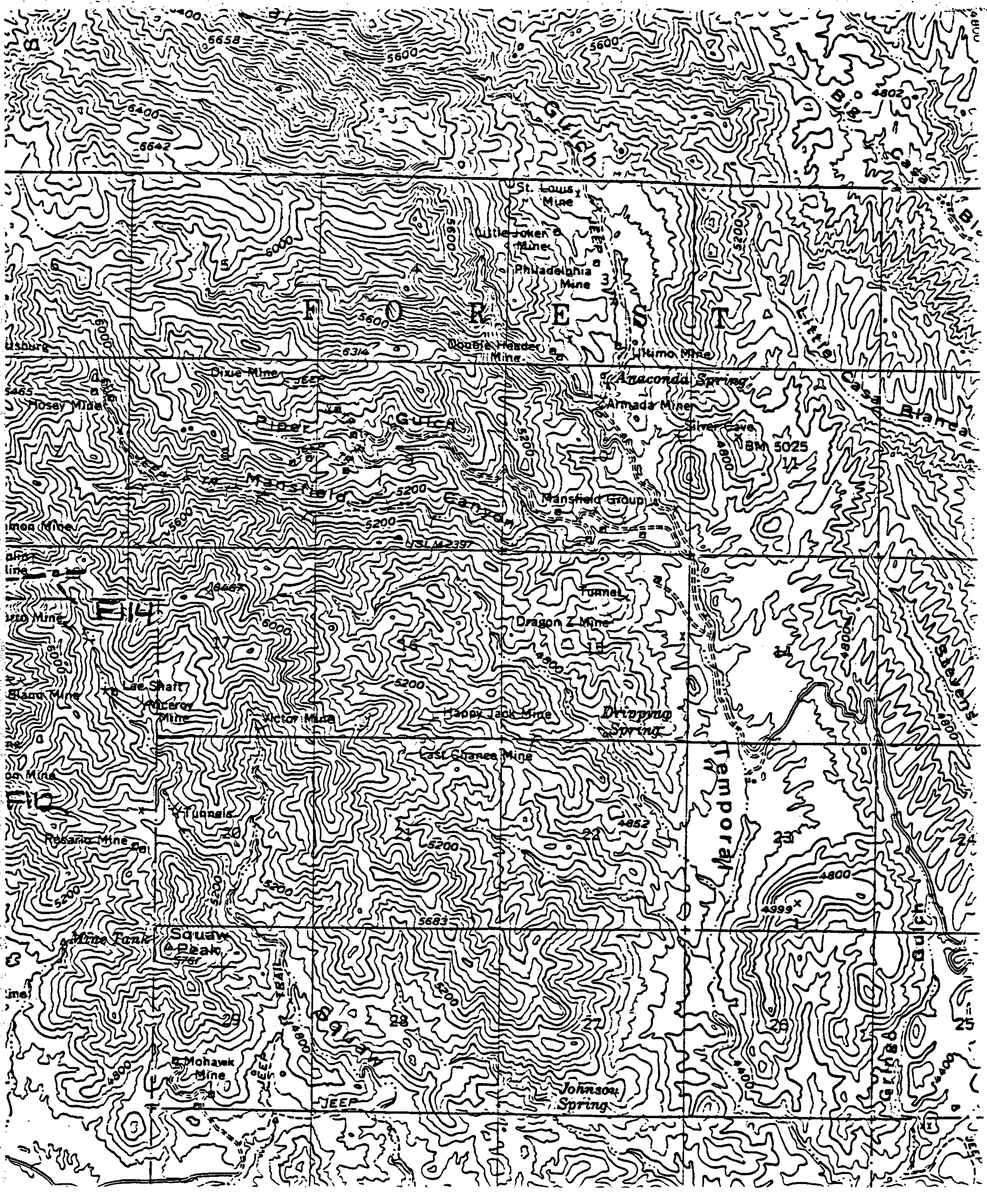

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Blanca
6314
Double Header Mine
Ultimo Mine
Dixie Mine
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Hosey Mine
Armada Mine
Piper
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Dragon Z Mine
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Gulch
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JEEP

GEOCHEMICAL AND GEOPHYSICAL TECHNIQUES IN RESOURCE ASSESSMENTS

USGS Research 1980, PP1175

GEOCHEMICAL RECONNAISSANCE RESULTS

Regional geochemical studies, Patagonia Mountains, Arizona

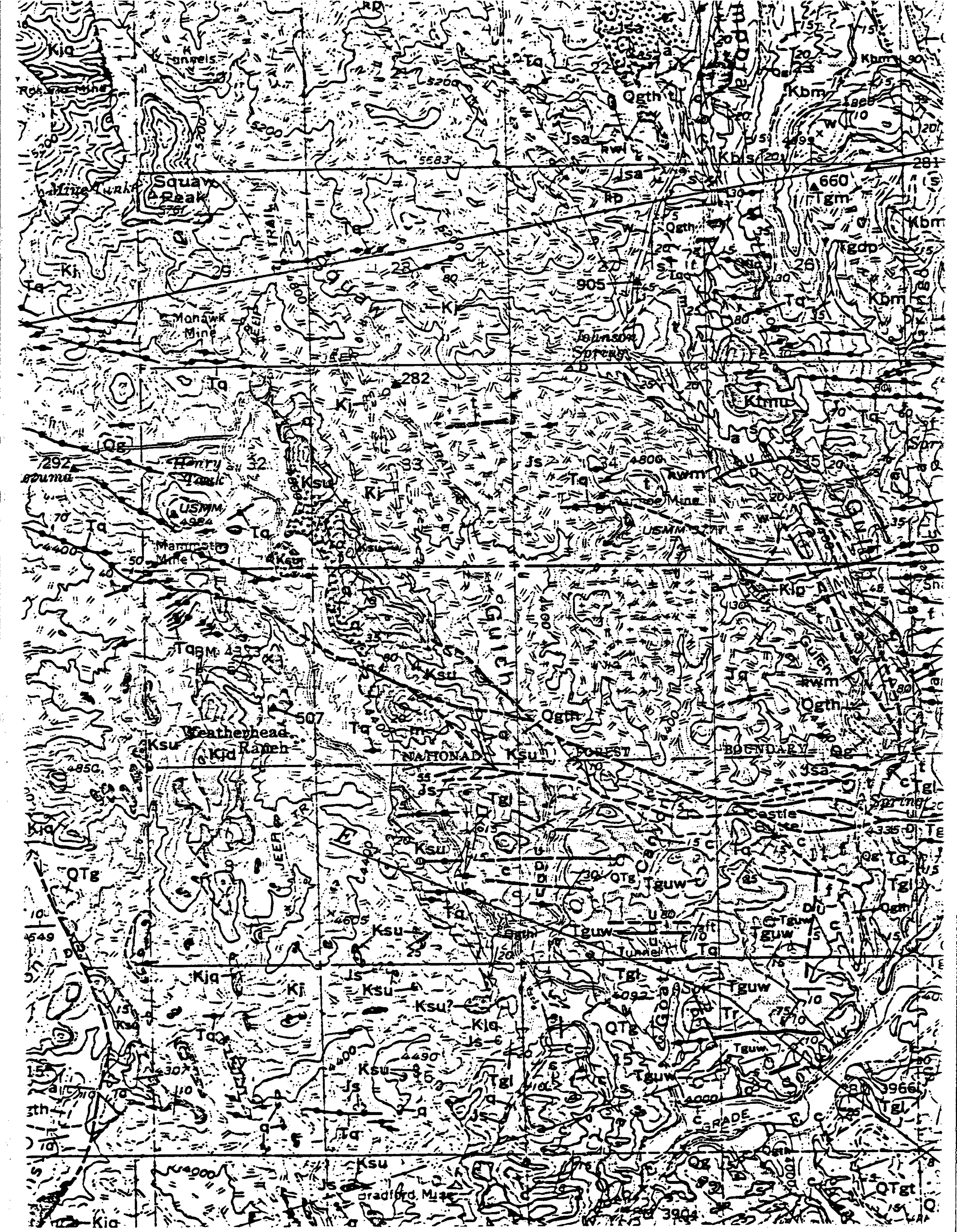
In the Patagonia Mountains, Santa Cruz County, Ariz., M. A. Chaffee, R. H. Hill, S. J. Sutley, and J. R. Watterson collected 300 stream sediment samples along drainages and analyzed them for 32 elements. In spite of the variety of rock types present throughout the Patagonia Mountains, background lead and tellurium concentrations throughout this range generally were found to be well above regional background concentrations determined for these elements in southern Arizona.

High concentrations of gold, tellurium, and boron and low concentrations of manganese occur in north-northwest-trending zones that transect the range roughly parallel to the major north-northwest structures and to the west of Red Mountain. Lead and silver anomalies correlate with each other throughout the Patagonias; copper anomalies do not coincide with those of molybdenum or any of the other elements studied.

The Red Mountain porphyry copper system is best delineated by high concentrations of molybdenum, lead, and tellurium coincident with low concentrations of manganese. The coincidence of this combination of elements elsewhere in the range suggests the presence of other blind porphyry systems.

Potential uranium mineralization, Mineral Mountains, Utah

In the Mineral Mountains area of the Richfield 2° quadrangle, Utah, W. R. Miller interpreted the results of uranium analysis and *Q*-mode factor analysis of 30 water and 29 stream sediment samples to indicate the potential for uranium deposits in the area. The most favorable areas are in a granitic pluton near its contacts with sedimentary and metamorphic rocks. The uranium anomalies most likely are derived from uraninite-bearing veins along faults and fractures within the pluton.



Squaw Peak
Mohawk Mine
Johnson Spring
Henry Tank
USMM 4984
Mammoth Mine
USMM 3777
Weatherhead Ranch
NATIONAL FOREST BOUNDARY
Gulch
Castle Butte
Tunnel
GRADE
Kjq
Kj
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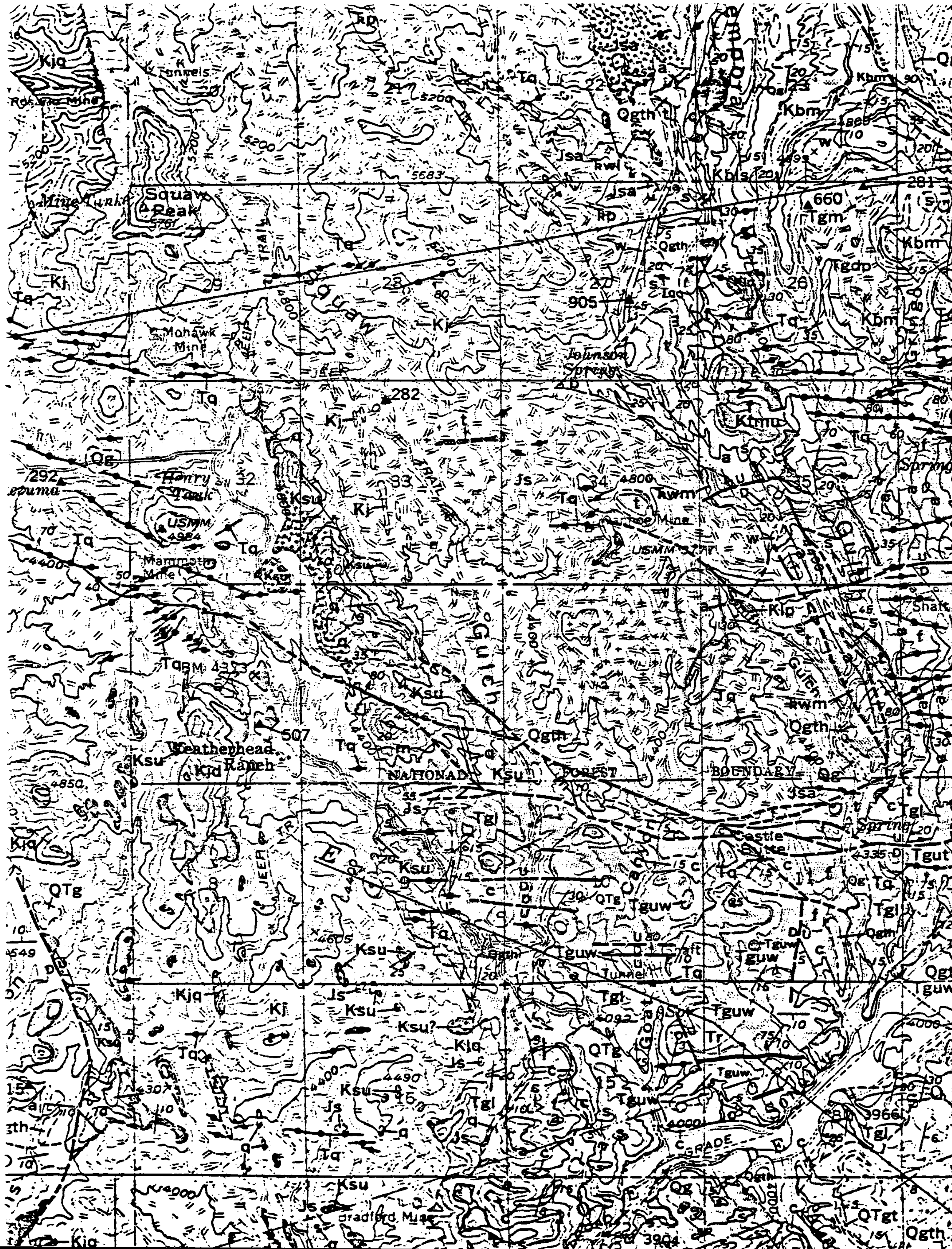


Tunnels
Squaw Peak
Mohawk Mine
Johnson Spring
Henry Tank
Mammoth Mine
Weatherhead Ranch
NATIONAL FOREST BOUNDARY
Castle Butte
Tunnel
Shaft
GRADE
Bradford Mine

A GEOCHEMICAL ANOMALY OF BASE METALS AND SILVER IN THE SOUTHERN SANTA RITA MOUNTAINS, SANTA CRUZ COUNTY, ARIZONA

By HARALD DREWES, Denver, Colo.

Abstract.—An area of Jurassic granite northwest of Patagonia, Ariz., altered in Paleocene (late Laramide) time, contains anomalous amounts of Cu, Pb, and Zn, and also contains sporadic anomalous concentrations of Au, Ag, and Mo. Background values of the three base metals are, respectively, about 15, 25, and 25 ppm. Samples in the altered area show concentrations of 2 to more than 100 times these background values, and over a substantial part of the area they are 5–16 times background values. The ore metals were introduced or mobilized during alteration; at the same time B, Sc, Ti, V, and Zr were concentrated in the altered rocks.

Results of current geological investigations in the Santa Rita Mountains southeast of Tucson, Ariz., indicate several groups of geochemically anomalous areas. One group of anomalies occurs largely within a zone of altered plutonic rocks that trends north-northwest roughly along the crest of the range. The location of the altered areas and their relation to various plutonic rocks and to some volcanic host rocks are shown on a preliminary geologic map of the Mount Wrightson quadrangle (Drewes, 1966). Very likely a zone of altered areas continues southeastward along Flux Canyon to Washington Camp in the Patagonia Mountains.

This article briefly describes the anomalous concentration of copper, lead, zinc, and silver in one of the largest and least prospected of these areas with altered rocks, which for brevity will be referred to as altered areas The area is located southeast of the old Ivanhoe mine, about 3 miles west-northwest of Patagonia. The Ivanhoe altered area, as it will be called here, is in a relatively inaccessible region and has not been as intensively studied as some of the other altered areas of this region. As a result, small prospects, common in most of the other altered areas, are virtually absent here. Indeed, most mines and prospects in the southern part of the Santa Rita Mountains are on quartz veins (Schrader, 1915). The only altered area that has received considerable attention is in the upper reaches of Mansfield Canyon, 4 miles north-northwest of the Ivanhoe area. A geochemical reconnaissance of the other altered areas suggests that they, too, contain anomalous concentrations of base metals.

GEOLOGY

The oldest rocks of the Ivanhoe altered area (fig. 1) are Triassic volcanic and sedimentary rocks and consist of intensely indurated and commonly finely laminated reddish-gray siliceous flows and tuffs, intercalated with thin lenses of quartzite. Clastic rocks are more abundant and more quartzose in this unit than in any of the younger ones. In places these clastic rocks contain crossbedding suggestive of an aeolian origin. Near the Ivanhoe altered area the Triassic rocks form a steeply dipping structural block only a few thousand feet thick, but in most of the Santa Rita Mountains these rocks are in a more gently eastward dipping homoclinal sequence about 10,000 feet thick.

Jurassic granite of Squaw Gulch intrudes the older volcanic and sedimentary rocks north of the area shown in figure 1, but locally it is probably faulted against them. The granite is part of a pluton at least 10 miles long; it commonly is a massive coarse-grained moderate-orange-pink rock, whose composition ranges from granite in the south to quartz monzonite in the north. Modes of virtually unaltered granite near the Ivanhoe altered area are listed in table 1. The orthoclase of these rocks is mildly but pervasively kaolinized, and the biotite is mostly chloritized.

Four sedimentary and volcanic rock sequences of Cretaceous and Tertiary age are shown together on figure 1. The oldest two sequences, lying to the east of the altered area, consist of arkosic conglomerate, volcanic conglomerate, rhyolitic tuffs, and dacitic flows,

U.S. GEOL. SURVEY PROF. PAPER 575-D, PAGES D176-D182

TABLE 1.—*Modes of unaltered granite near Ivanhoe altered area*

	Sample No.			
	184	209	229	249
Quartz	37.4	31.2	12.0	23.2
Orthoclase	45.0	57.2	46.2	37.6
Albite	14.9	9.7	35.2	36.1
Biotite	1.3	1.1	2.4	2.0
Magnetite	1.0	.7	.7	.9
Apatite	.2	.05	.6	.05
Zircon	.2	.05	.05	.05
Amphibole(?)			1.1	
Sphene			1.7	
Tourmaline	.05			.2
Total	100.05	100.0	99.95	100.1

which lie unconformably on the granite. They are probably of Early Cretaceous age. The granite debris in the arkosic rocks was derived from the Jurassic granite. The third sequence, lying to the west, near the Ivanhoe mine, also contains arkoses derived from the granite, lies unconformably on it, and contains at least some rocks of Late Cretaceous age. These three sequences were mildly chloritized, epidotized, and argillized during emplacement of assorted plutons and dikes of Laramide age that are not exposed in the area shown in figure 1. The youngest sequence of post-granite volcanic and sedimentary rocks occurs south of the granite and consists of rhyodacitic tuffs and volcanic breccia, which unconformably overlie a Cretaceous pluton southwest of the area shown in figure 1.

Quartz veins, here usually only a few feet thick, cut all these rocks, as well as some of the intensely altered granite. However, inasmuch as some hundred similar veins are not surrounded by altered areas, the veins are probably younger than the alteration, rather than contemporaneous with it. Many of the veins carry base metals, and some have been mined for silver in the nearby Wrightson and Tyndall mining districts. The Ivanhoe mine (fig. 1), described by Schrader (1915, p. 216–218), produced some lead, silver, and gold from a quartz vein.

The geologic structure is relatively simple near the Ivanhoe altered area. Vestiges of a pre-Paleocene fault trend north-northwestward within and along the Triassic rocks along Temporal Gulch (lower right-hand side, fig. 1). This fault is probably related to, or was a part of, a major fault(?), along which (1) many intrusives were intruded from Triassic time onward, (2) movement has differentially tilted the blocks on either side of the mountains, and (3) fluids moved that altered and mineralized some rocks (Drewes, 1966). Another group of faults, which splay out to a broad west-trending zone at Temporal Gulch, join west of the area shown in figure 1 to form a major fault that swings northwestward. Some quartz veins lie in this fault system and some are brecciated by late movement along it. These faults are a result largely of Paleocene (Laramide) deformation. The Ivanhoe altered area lies near the intersection of the inferred pre-Paleocene fault and two branches of the younger fault system.

The main altered area, southeast of the old Ivanhoe mine, forms an irregular ellipse slightly more than half a square mile in extent. Several smaller patches of altered granite lie southeast and northwest of the main area. Scrub growth, particularly manzanita, is markedly denser in the altered area than around it. Local relief is about 500 feet, and the gullys are narrower than those in unaltered granite terrane. Outcrops are abundant, small, and irregular on the slopes but are more extensive along the gully bottoms; they are mostly more silicified or less intensely fractured altered rock, resulting in at least one bias in the sampling. The altered rock is vividly colored in reddish-brown, yellowish-brown, and pale-yellowish-gray hues. Relict granitic textures are still discernable in all but the most intensely altered rock. Breccia texture appears only in the two small volcanic bodies at the north edge of the altered areas; presumably these are remnants of a capping sheet, but they may be intrusive bodies. Fractures are much more abundant in the altered than in the unaltered granite, and the most abundant concentration of iron oxides is along this fracture network. Bulk rock X-ray diffraction analyses of 17 specimens show that the altered rocks are made up of at least 25 percent of clay minerals, which consist of about equal amounts of the kaolin and sericite groups. Alunite makes up an additional 5–10 percent of about a third of the specimens. Sulfides have not been seen in outcrop, but pyrite boxwork structures are preserved in some iron oxide fracture filling. A few jasperoid veinlets are also present. The alteration is probably of late Paleocene (late Laramide) age, because some plutons of Paleocene age are similarly altered but younger rocks are not.

SAMPLING AND RESULTS OF ANALYSES

Reconnaissance sampling of alluvium showed the presence of anomalous amounts of base metals in several local basins between Squaw Gulch and Temporal Gulch. The initial chip samples of rock were chosen to show primarily what metals remained in the various types of altered rock rather than their areal distribution; the samples consisted of as many as eight chips each, and each chip was analyzed indi-

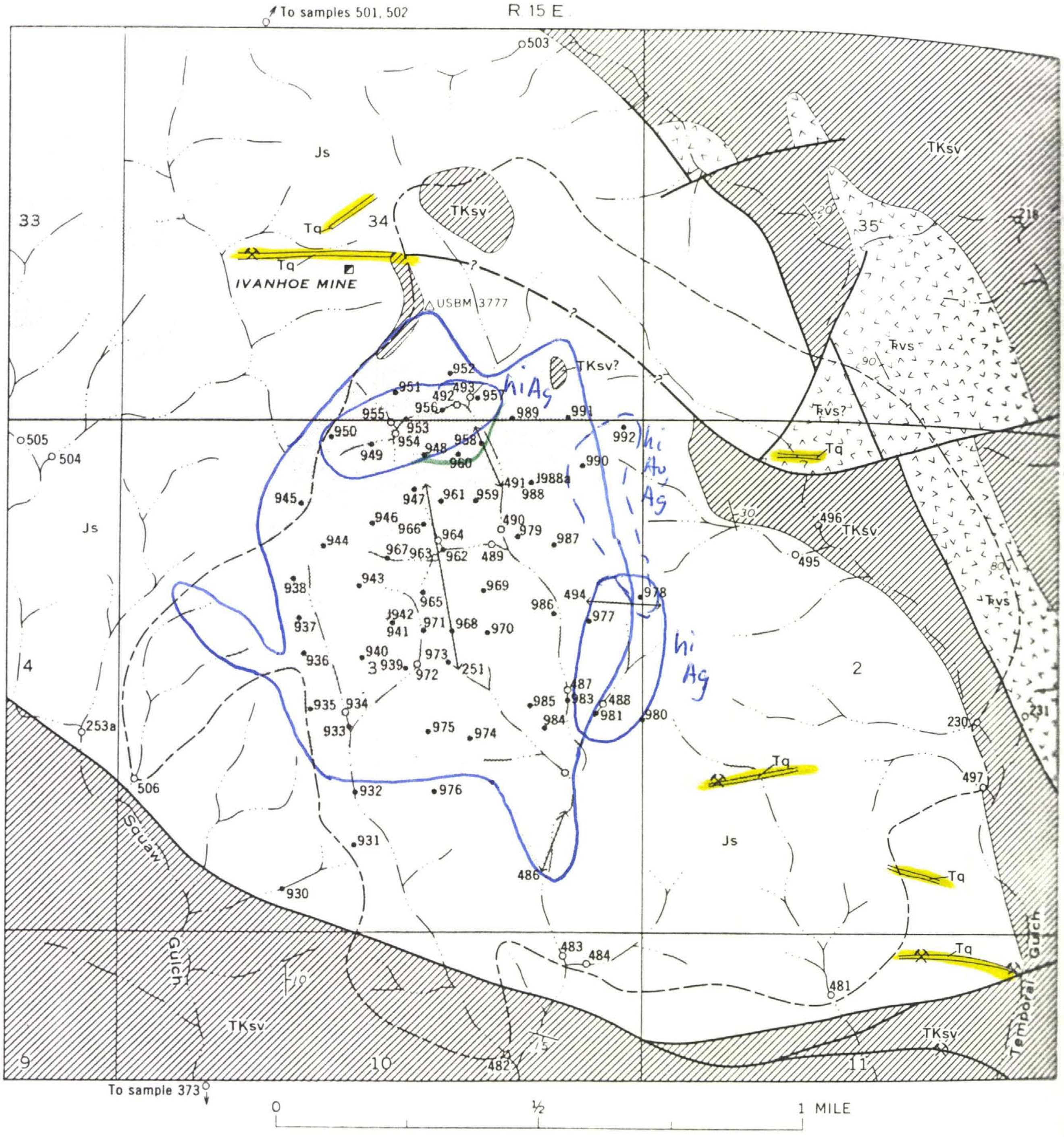
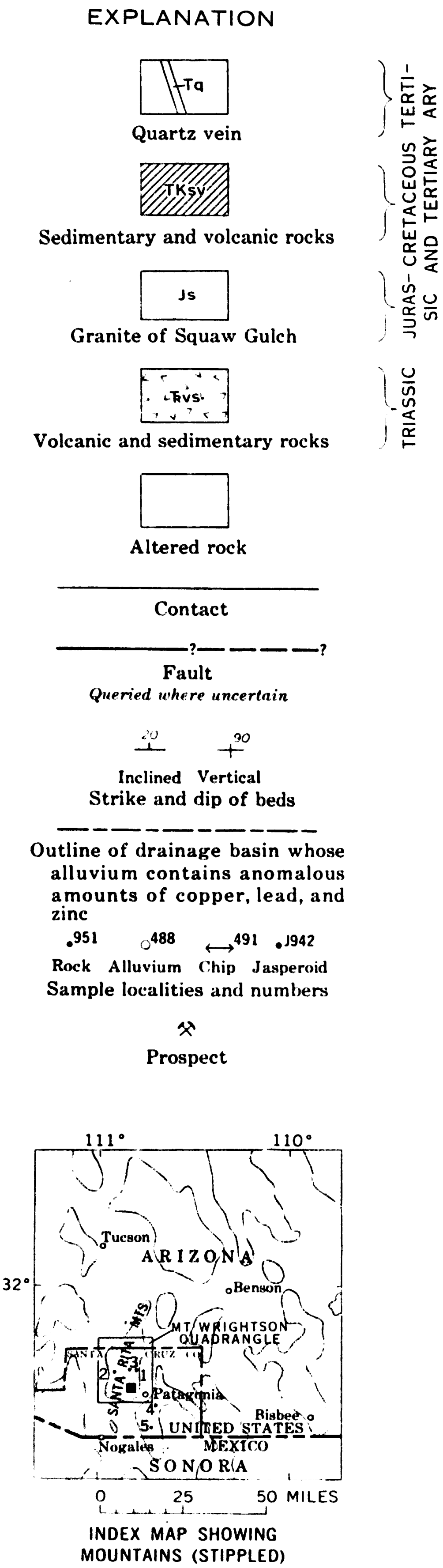


FIGURE 1.—Generalized geologic map of the Ivanhoe altered area, Santa Rita Mountains, Ariz. Index map shows following locations: 1, Wrightson mining district; 2, Tyndall mining district; 3, Mansfield Canyon; 4, Flux Canyon; 5, Washington Camp; 4–5, Patagonia Mountains area.



vidually. Final sampling was concentrated on the most altered rocks to get a general idea of the distribution of selected metals. Each of these samples consisted of three to six chips of the most altered rock types, such as may appear along fractures, and were collected within about 100 feet of each other. Composites of these chip samples, as well as of the individual alluvial samples and initial chip samples (about 110 in all) were analyzed for copper, lead, and zinc by the wet chemical methods described by Ward and others (1963) and by semiquantitative spectrographic methods. Gold was analysed for only in the altered rock samples, using atomic absorption methods. The chemical analyses were made by T. F. Harms, K. W. Leong, Elizabeth Martinez, J. B. McHugh, C. S. E. Papp, and Eric Welch, and the spectrographic analyses by Jerry Motooka, Elwin Mosier, and D. M. Valiere.

Background values for unaltered granitic rocks of the Santa Rita Mountains are about 15, 25, 25 parts per million, respectively, for copper, lead, and zinc. These values were obtained from many rock analyses and selected alluvial analyses (table 2). They are roughly valid for a total of 46 rock analyses, but certain dioritic rocks, for example, may have slightly higher background values for copper. Thus an estimated average background value for copper is about 15 ppm. However, to be on the safe side, in figure 2 a copper background value of 20 ppm is used. An additional 10 samples of alluvium taken from granitic basins also show about the same background values for copper and lead, and they provide the only detailed values for zinc.

TABLE 2.—*Source of data for background values of copper, lead, and zinc in samples from the Santa Rita Mountains, Ariz.*

Rock type (unmineralized)	Number of samples	Median content of metal (ppm)		
		Cu	Pb	Zn[1]
Semiquantitative spectrographic method				
All plutonic rocks	46	30	15	<200
Granitic rocks	33	~12	15	<200
Jurassic granite	5	7	~25	<200
Wet method				
Jurassic granite	4	10	≦25	25
Alluvium from granitic basins	10	15	<25	25
Estimated background values of Ivanhoe altered area	------	15	25	25

[1] Threshold of detection by semiquantitative spectrographic method is 200 ppm.

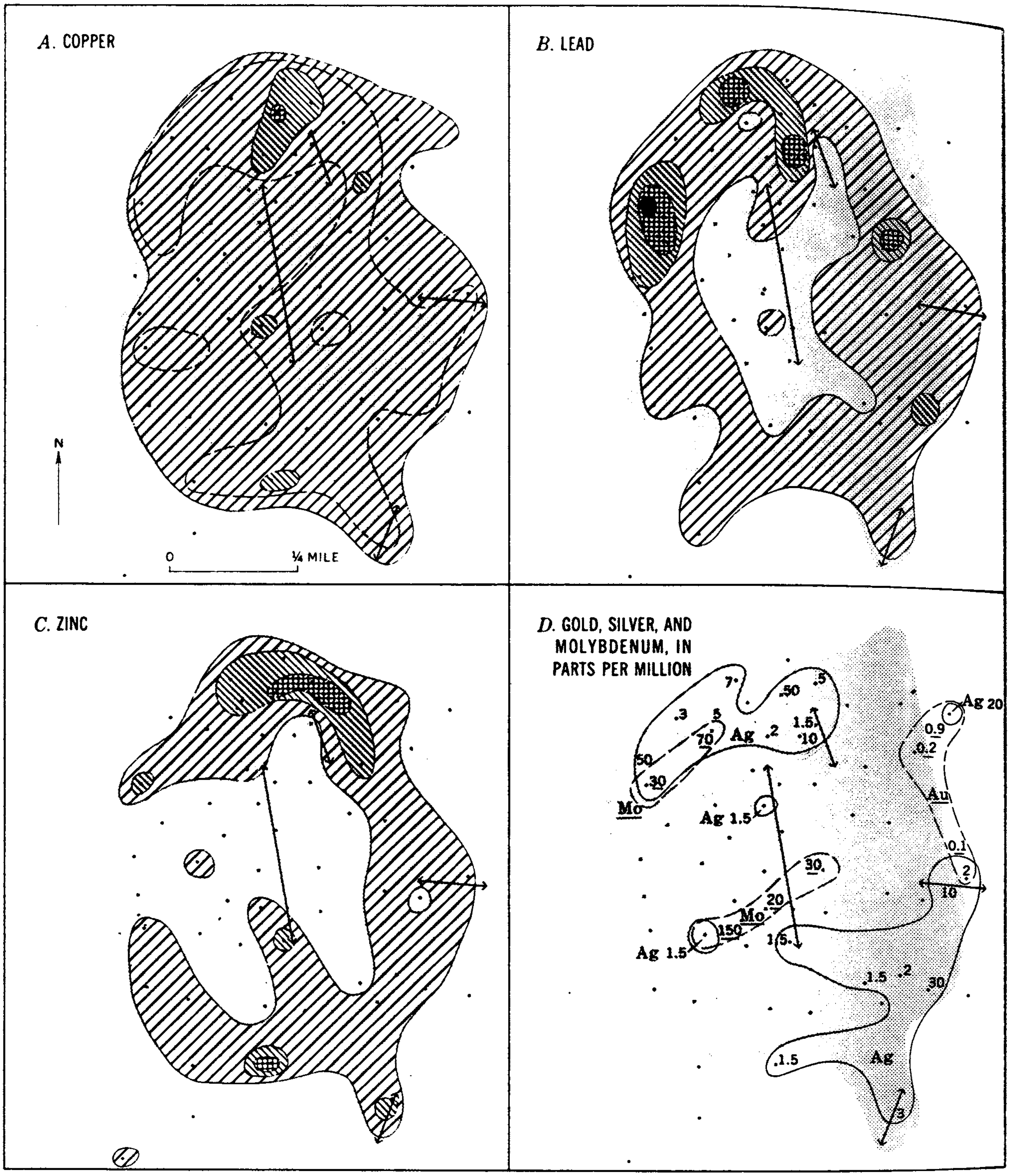


FIGURE 2.—Maps showing the distribution of copper (*A*), lead (*B*), zinc (*C*), and gold, silver, and molybdenum (*D*) in the Ivanhoe altered area, Arizona.

EXPLANATION

a b

Altered rocks
Showing location of samples (a) *and line of chip samples* (b)

CONTENT OF COPPER, LEAD, AND ZINC, IN PARTS PER MILLION, AND IN RELATION TO BACKGROUND

Lead and zinc, 50-150 ppm
Copper, 40-150 ppm
2-6×background

150-400 ppm
6-16×background

400-2,000 ppm
20-100×background

More than 2,000 ppm
>100×background

Maximum values of copper, lead, and zinc in rocks obtained from the Ivanhoe altered area are 500, 15,000, and 1,200 ppm, respectively. The distribution of copper, lead, and zinc in the Ivanhoe altered area is shown in figures 2*A*-*C*. The values are contoured in terms of the background; that is, the field between the × 2 and × 6 contours, or isopleths, contain only samples having values of a particular metal of 2 to 6 times its background value. In general, data obtained by the wet method are in close agreement with that obtained by semiquantitative spectrographic methods. However, the contours have been constructed to show the highest values where the two methods were not in full agreement.

The base-metal anomalies are crudely annular, the highest values being located near the margin of the altered area. Reasons for this distribution, such as an increase in alteration or fracture density near the margin of the anomalous areas, were not observed in the field. Possibly there has been an outward movement of these metals from the center of the altered area, and zinc and lead retained their mobility after some copper had become fixed.

In addition to the anomalously high values of three base metals, some samples contain silver (as much as 50 ppm), gold (as much as 0.9 ppm), and molybdenum (as much as 150 ppm). The concentration and distribution of these elements are shown in figure 2*D*. A single sample (No. 945) also contains both antimony (300 ppm) and beryllium (30 ppm), and two other samples (Nos. 956 and 981) each contain 150-200 ppm of bismuth. Again, most of the samples with high concentrations of these metals are near the margin of the altered area, especially along the northern and eastern sides. The highest gold content was actually obtained from locally altered rock adjacent to quartz-filled fractures outside the intensely altered area.

Semiquantitative spectrographic analyses for 20 elements are summarized in figure 3. The ranges, shown by the bars, and the median values, shown by the symbols on the bars, are given for four groups of samples, of which two groups are of unaltered rocks to provide background data. Among the values for the unaltered rocks, the abundances of the trace elements are given separately for the 5 samples of Jurassic granite, and to augment the relatively few samples of that granite, abundances for 33 samples of all granitic rocks in the area are also given. These include the Jurassic granite, as well as several bodies of quartz monzonite and of granodiorite and one of monzonite. Thus, in addition to minor compositional variation, the group of 33 samples also represents rocks exposed at different levels in each pluton. Comparison of the first two bars (median values) for each element shows that the elements Ag, B, Ga, La, Mo, Ni, Pb, V, Y, and Zn are about equally abundant in the Jurassic granite and in all granitic rocks of the area. Ba, Co, Cr, Cu, Mn, Sc, Sr, Ti, and Zr are less abundant in the Jurassic granite, and only Be is more abundant in this granite than in the other rocks.

Additional analyses of tellurium on about half of the specimens show a distribution roughly comparable to that of lead or zinc, and show concentrations to 6.3 ppm which is several orders of magnitude more than could be expected in granite.

An increase of the mean values of Ag, B, Cu, Mo, Pb, Sc, Ti, V, and Zr in the altered rocks, compared with the unaltered ones, suggests that these elements were concentrated or added during the alteration. Likewise, the altered rocks were impoverished in La, Be, and Mn. The Ba, Ga, and Y content of the altered rocks and unaltered rocks is about the same. Poor sensitivity of the analytical technique for the other elements does not permit any significant comparison to be made for them.

The higher content of Ba, Cu, Mn, Pb, and Zn in alluvium derived from the altered rocks than in the

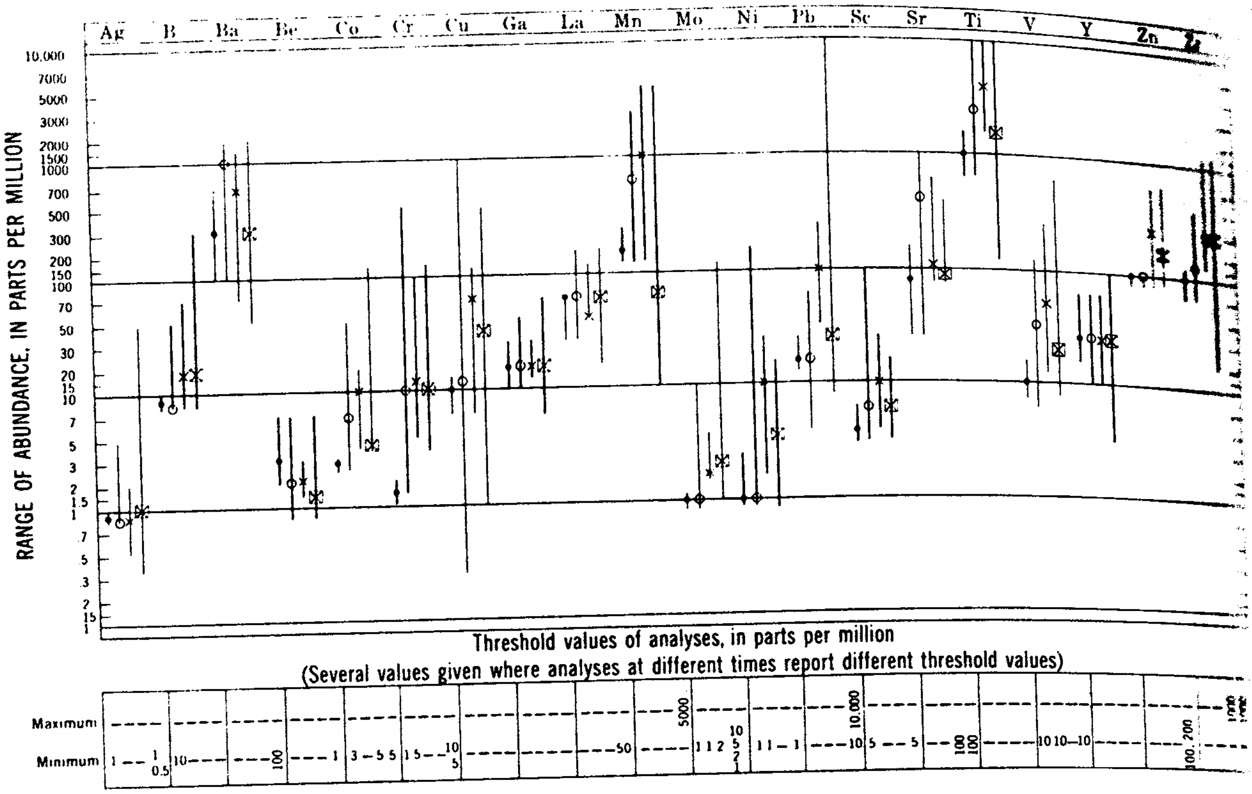


FIGURE 3.—Range of abundance and median value of some trace elements in 5 samples of Jurassic granite of Squaw Gulch (●), 33 samples of all granitic rocks of the Santa Rita Mountains, Ariz. (○), 28 samples of alluvium derived wholly or largely from altered granite of Squaw Gulch (X), and 55 samples of altered granite of Squaw Gulch in the Ivanhoe area (⊠). Trace elements looked for and not found, or found only rarely, include As, Cd, Nb, Sn, and W. Threshold value of analyses only given for elements some of whose reported abundance lie close to that value.

altered rocks themselves is noteworthy, and suggests that in altered areas close comparison between results obtained on alluvium and rock samples may be difficult to make. Possibly some elements are concentrated in organic compounds present only in alluvium derived from altered areas but absent in altered rock.

Samples of two jasperoid veinlets from the altered area were also analyzed. Other than copper (200–300 ppm), they contain much less of the other elements than do the altered rocks in which they appear.

CONCLUSIONS

Reconnaissance indicates that the Ivanhoe altered area has a fairly extensive tract of ground underlain by altered granite that is enriched in copper, lead, zi[nc,] silver, and other elements. Surface examination, a[nd] reconnaissance sampling, shows several similar ar[eas] of altered and mineralized rocks in a north-northwe[st] trending belt in the Santa Rita Mountains.

REFERENCES

Drewes, Harald, 1966, Preliminary geologic map of the Wrightson quadrangle, Santa Cruz and Pima Count[ies,] Arizona: U.S. Geol. Survey open-file report.

Schrader, F. C., with contributions by Hill, J. M., 1915, Min[eral] deposits of the Santa Rita and Patagonia Mountains: [U.S.] Geol. Survey Bull. 582, 373 p.

Ward, F. N., Lakin, H. W., Canney, F. C., and others, 1[963,] Analytical methods used in geochemical exploration by [the] U.S. Geological Survey: U.S. Geol. Survey Bull. 1152, 10[0 p.]

Troy. At the Rattler or Manhattan mine, magnetite, chalcopyrite, and pyrite as a fine-grained aggregate contained 27 to 30 percent iron, 3 to 3.7 percent copper, 27 to 30 percent silica, 1 percent lime, 20 percent magnesia, and some gold and silver. Character samples of the better magnetite on the Buckeye and Rattler claims contained 37 to 60 percent iron and 0.02 to 1.0 percent titania.

The magnetite deposits were poorly exposed in 1961. They appeared as irregular replacements, more or less paralleling the bedding in small fault blocks of Mescal limestone associated with diabase and granitic intrusives. Individual replacement bodies appeared small; however, the host Mescal limestone is exposed as complex and comparatively small fault blocks for many miles in the Dripping Spring Mountains both northwest and southeast of Troy (57, pp. 12, 22).

Miscellaneous

Gold placer mining operations in the Tucson district indicated the presence of abundant magnetite and some hematite and ilmenite in alluvium of the area (17, pp. 1180-1181).

Santa Cruz County

Copper Mountain Hematite-Limonite

Hematite and limonite occur on the Copper Mountain group of claims 3 miles east of Patagonia (77, fig. 1), approximately in sec 9, T 22 S, R 16 E, Gila and Salt River meridian and baseline, on the south side of Red Rock canyon. The outcrop stands out as a 150 foot high and 70 foot thick ledge of red, ferruginous, leached, and silicified rhyolite, striking N 60° W. The rhyolite is pitted with pyrite casts, and some of it is heavily impregnated with iron oxides. Adjoining gravels are cemented by hematite and limonite. Croppings above and 200 feet southeast are weakly stained with malachite and azurite. A character sample taken by the Bureau in 1961 contained 18.5 percent iron, 1.0 percent titania, 0.1 percent manganese, 0.08 percent phosphorus, 0.48 percent sulfur, and 49.2 percent silica. The deposit is too low-grade and small to be considered a source of iron. Other similar and small deposits occur in the area (62, p. 245).

Line Boy Magnetite-Hematite

Hematite was reportedly abundant at the Line Boy mine near Duquesne (78, fig. 1). The mine is at 5,400 feet altitude on the east flank of the Patagonia Mountains, approximately in sec 22, T 24 S, R 16 E, just north of monument 113 on the United States-Mexico border. The property is reached by traveling over 5 miles of access road south of Duquesne.

A 3-foot thick sheet of fine-grained, friable, and nearly pure specularite is exposed in an adit along the hanging wall side of a 10-foot wide, fine-grained granite porphyry dike that trends west-northwest and has a steep north dip.

The property was developed as a copper prospect, the ore containing bornite, chalcopyrite and pyrite. The deposit is considered small (62, pp. 347, 348).

Yavapai County

Introduction, Precambrian Taconite- and Jaspilite-Like Iron Formations in Yavapai and Maricopa Counties

Magnetite and some hematite were noted in low-grade taconite, semitaconite- to jaspilite-like iron formations, observable in an interrupted pattern more than 70 miles through Yavapai and extending south into Maricopa County (fig. 19) as part of the great Yavapai series. Geographically, the iron formation centers around Cleator-Crown King and extends north beyond Lynx Creek into Tps 16 and 17 N, Rs 1 and 2 W, and south into the Hieroglyphic Mountains, T 6 N, Rs 1 and 2 W, in Maricopa County, Gila and Salt River meridian and baseline. The east-west limits extend beyond Mayer and Stanton.

The Yavapai series consists of metamorphosed volcanic and sedimentary rocks, including diorite, rhyolite, greenstone, quartzite, phyllite, argillite, graywacke, mica schist, hornblende schist, and amphibolites.

The iron-rich formations investigated varied from jaspilite-like beds to predominantly taconite-like occurrences. The area, approximately 35 miles wide and 70 miles long (fig. 19) was too great for comprehensive evaluation and would necessitate extensive geologic investigation, correlation, and basic exploration. However, a number of outcrop areas were given a reconnaissance examination to develop information as to their extent and continuity and were character sampled to form some idea as to their mineral potential. The chemical analyses of character samples in this taconite and jaspilite iron formation are summarized as table 16. The areas investigated X-1-X-21, fig. 19) are mostly in Yavapai County. The 100-million-ton (20) Hieroglyphic Mountains occurrence (X-21) and the extensive Big Boulder taconite (X-20) are reported in Maricopa County.

The jaspilite- and taconite-like areas investigated in Yavapai County (X-1-X-19, fig. 19) are discussed as follows:

Black Hills Magnetite-Hematite Jaspilite

General

Magnetite and hematite occur in numerous jaspilite beds about 8 miles northeast of Dewey in the Precambrian Grapevine Gulch formation (figs. 34, 35, and 36) in the Black Hills, Tps 14, 14½, and 15 N, R 2 E. The beds are part of a thick sequence of steeply dipping fine-grained tuffaceous rocks and chert that trend south-southeast through Yaeger Canyon Ranger Station, Kendall Camp, and beyond the old Black Chief (Warrior) mine. The best exposures are in secs 2, 3, 4, 9, 11, 12, 24, T 14 N, R 2 E, and secs 17, 19, T 15 N, R 2 E, and are reached from Dewey and Yaeger Canyon Ranger Station over difficult access roads and trails.

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Metal Zoning in the Patagonia Mountains, Arizona

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ABSTRACT

The geology of the Patagonia Mountains is dominated by a large Laramide granodiorite pluton which intrudes a compositionally diverse suite of wall rocks. The area hosts a variety of mineral deposits including disseminated Cu and Ag, breccia pipe, vein, and limestone replacement ores. Data from 95 mineral deposits varying in size from prospect pits to mines with important production and reserves were used to construct zoning maps based both on absolute metal abundance and on relative metal abundance expressed as a metal ratio.

Zoning in terms of absolute metal abundance is symmetric about the pyritic zone centered on the Sunnyside mine. Here, a central zone of mineral deposits containing abundant Cu-As is surrounded by successively more outlying zones of Zn, Pb-Ag, and Mn. Similar zoning which is less well developed and apparently lacks Mn is also present at Red Mountain. Both zoning sequences are circular and about 6 miles in diameter. The obvious conclusions, of some practical significance, are that the hydrothermal fluids which formed the pyritic zones also carried abundant metals and that where water/rock was high larger amounts of metal may have been deposited. The circular symmetry of the metal zones suggests that the hydrothermal fluids moved radially outward from the centers of disseminated pyrite.

Zoning of the metal ratios Cu/Ag, Pb/Zn, Pb/Ag, and Cu/Pb is well developed and contours drawn on a district scale encompassing the entire Patagonia Mountains are parallel to the long axis of the granodiorite pluton. Metal ratio contours extend without offset through a highly variable suite of rocks and several alteration zones which suggest that reactions between the wall rock and the hydrothermal fluid had little effect on the relative amount of metal deposited. This is supported by limited data which indicate that metal ratios in a specific mine vary by less than a factor of 4 in different host rocks as compared to variations of metal ratios on a district scale which commonly exceed a factor of 10,000. It is concluded that temperature variations controlled the relative amount of each metal deposited, expressed as a metal ratio, and that the metal ratio contours are parallel to isothermal contours established following emplacement of the granodiorite pluton.

In porphyry copper systems mineral deposits with high relative and absolute Ag contents are generally confined to the outermost metal zones. This relationship is well defined in the Patagonia Mountains.

INTRODUCTION

The Patagonia Mountains are located in Santa Cruz County, Arizona, 60 miles southeast of Tucson. They lie along a well-known alignment of porphyry copper deposits extending northwesterly from the Nacozari-La Caridad area in Sonora to Sacaton, Arizona and perhaps to Mineral Park, Arizona. The Patagonia Mountains host numerous mineral deposits with diverse geologic characteristics which are distributed over a large area and which all formed during or immediately following emplacement of a large differentiated Laramide granodioritic pluton.

This paper will describe and interpret lateral zoning patterns on a regional basis encompassing the entire mountain range. It is based on work done for the Southwestern Exploration Div. of ASARCO Incorporated in 1971 and later presented to a symposium sponsored by the Arizona and New Mexico Geological Societies in Silver City, New Mexico (Graybeal, 1975). Inclusion of these data in AGS Digest 15 provides one example of the position of Laramide precious metal deposits, including the important Hardshell silver deposit which is described elsewhere in this volume, in a typical and well-zoned Laramide hydrothermal setting.

GENERAL GEOLOGY

The Patagonia Mountains are dominated by a large Laramide intrusion (Fig. 1) which is 5 miles wide along the international border and narrows northward over a distance of roughly 12 miles, where it is terminated in an area of complex intrusion breccia and north-striking comagmatic dikes. It is composed of several textural varieties of granodiorite with small areas of quartz monzonite and diorite. All phases are locally porphyritic. The greater width of the intrusion along the international border suggests this area may be more deeply eroded than exposures farther north. Little published data are available concerning the Sierra de San Antonio, which is the southern extension of the Patagonia Mountains in Sonora.

Wall rocks into which the granodiorite pluton was emplaced are diverse. Precambrian varieties are largely granitic with minor amphibolite. Two blocks of Paleozoic rocks which include Bolsa Quartzite through Concha Limestone (minimum aggregate thickness of 4500 ft.) occur on the east side of the granodiorite pluton. Mesozoic rocks are most abundant at the north end of the Patagonia Mountains and include Triassic volcanic rocks, Jurassic granitic plutons, Cretaceous sedimentary and volcanic rocks, and numerous felsic ash flow tuffs, breccias, and trachyandesite flows all of late Cretaceous age. Small areas of Paleocene felsic tuffs are present north of the Laramide granodiorite. Further details of the geology can be found in Baker (1961) and Simons (1972 and 1974). The abundance of younger sedimentary and volcanic rocks at the north end of the Patagonia Mountains also suggests that this area is less deeply eroded than the southern end.

The most prominent structure in the Patagonia Mountains is the Harshaw Creek Fault, which separates

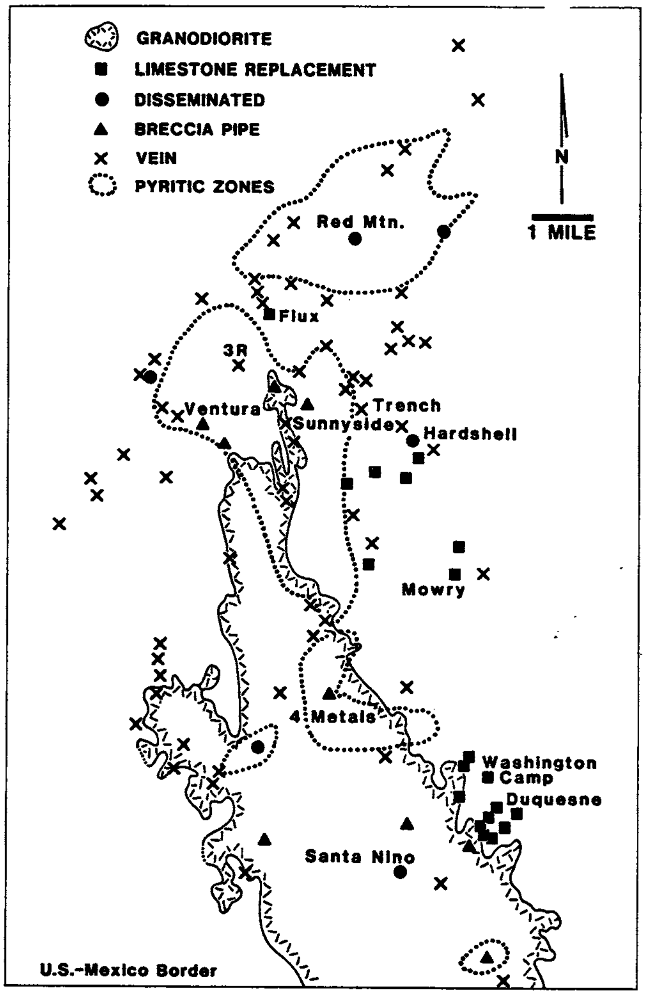

Figure 1. Location and type of mineral deposits relative to important geologic features in the Patagonia Mountains. Names shown for some of larger mineral deposits.

moderately deformed sedimentary rocks of the Cretaceous Bisbee Group on the west from the Paleozoic section near American Peak on the east. This fault may be either a strike-slip fault or a ring fracture along the west side of a Laramide caldera. Many of the mineral deposits in the area occur in or adjacent to fissures, faults, and breccias and it is clear that structures exerted a strong influence on the flow of hydrothermal fluids and thus the abundance of mineral deposits.

MINERAL DEPOSITS

Three large pyritic zones are shown on Figure 1. The zones centered on Red Mountain and the Sunnyside mine contain pyrite or its oxidized products primarily in the disseminated form along with quartz, sericite, alunite, pyrophyllite, and kaolinite. The pyritic zone near the 4 Metals mine and several smaller zones to the south and west contain pyrite largely in discrete quartz-sericite veins. Outcrops within the areas of pyritic veins may also contain hydrothermal biotite, potassium feldspar, and apatite. The variation from silicate alteration assemblages at outcrop level which are characteristic of the potassic zone in porphyry copper systems at the south end of the range to assemblages at outcrop level which are characteristic of the advanced argillic zone at the northern end of the range also suggests that the northern portion of the Patagonia Mountains is less deeply eroded than the southern portion.

Within and outside the areas of abundant pyrite are numerous sulfide mineral deposits varying in size from small prospect pits to mines with important production and reserves which are classified into 4 groups on Figure 1. Generally, the disseminated deposits are the largest and include the Red Mountain porphyry copper deposit (Corn, 1975) and the Hardshell silver deposit (Koutz, 1983). Next in size are breccia pipe deposits, of which the 4 Metals copper deposit (Graybeal, 1973) and the Ventura Mo-Cu deposit (Northern Miner Press, 1970) are the best known. They are largely confined to granitic intrusive rocks. Limestone replacement deposits, including the skarns at Washington-Duquesne (Lehman, 1980), the massive pyritic replacement at the Flux mine, and the manganiferous replacements at the Mowry mine, would probably rank next in size. The most variable in size and most numerous are sulfide veins, of which the Trench mine was the largest. Veins occur in virtually all rock types.

The first mining settlement in the Patagonia Mountains was at the Mowry mine which was located about 1855 (Schrader, 1915). The last mine to operate on a regular basis was the Flux, which closed in 1959, and there has been no significant mining since that time. Production from the Patagonia Mountains is estimated on Table 1 and substantial reserves still remain.

Table 1. Metal Production in the Patagonia Mountains, Arizona

Cu -	31.8 million lbs.
Mo -	9.0 million lbs.
Pb -	165.4 million lbs.
Zn -	203.2 million lbs.
Ag -	8.5 million oz.

METAL ZONING

This paper is concerned entirely with hypogene district zoning of metals in 95 mineral deposits distributed over a 100-square-mile area which are located on Figure 1. Zoning of metals in individual mineral deposits or in bulk rock samples in altered zones is not discussed. Mineralogical and assay data are largely from Schrader (1915) and from Asarco files, which are rather extensive due to custom ore shipments made to the Trench mill.

Zoning of Individual Metals

Detectable amounts of the metals discussed below can be found in most of the mineral deposits in the Patagonia Mountains. However, upon review of various production data it is clear that in most deposits only one or a few metals can be considered abundant in a qualitative sense and that deposits where certain metals are abundant tend to cluster in zones. Although supergene leaching and enrichment have modified the metal content of many deposits in the Patagonias, the modifications do not significantly distort zoning patterns based on abundance.

Copper

Cu is abundant as enargite, tennantite, tetrahedrite, and chalcopyrite in a northwest-elongate zone within and immediately adjacent to the granodiorite pluton (Fig. 2) with an easterly bulge toward Red Mountain. The widespread distribution of Cu reduces its effectiveness as a specific exploration guide, but it provides a clear indication of the Cu potential of the Patagonia Mountains.

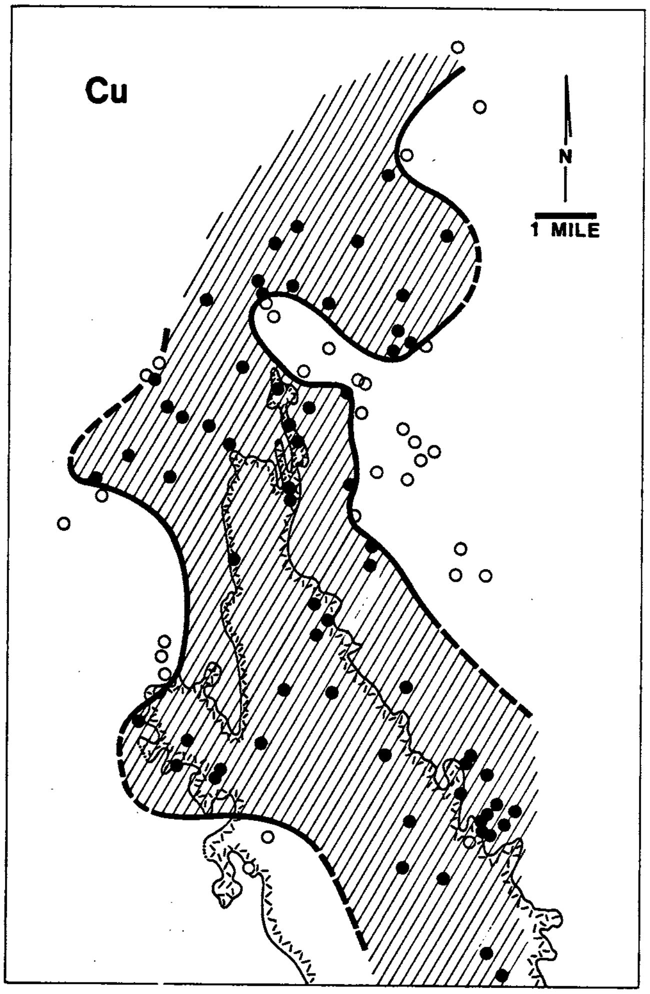

Figure 2. Distribution of mineral deposits containing abundant Cu in the Patagonia Mountains. Solid circles where Cu is abundant, open circles where Cu is scarce. Outlined Patagonia granodiorite in Figures 2-15 is same as shown in Figure 1.

Arsenic-Antimony

As and Sb occur largely in enargite, tetrahedrite-tennantite, pearceite, and pyrargyrite at the north end of the range and in arsenopyrite at the south end (Fig. 3). Zoning is well developed in a variety of rock types just north of the granodiorite pluton where a Cu-As core is successively enveloped by Cu-As-Sb and Ag-As-Sb zones. This zoning is not recognized elsewhere in the Patagonia Mountains,

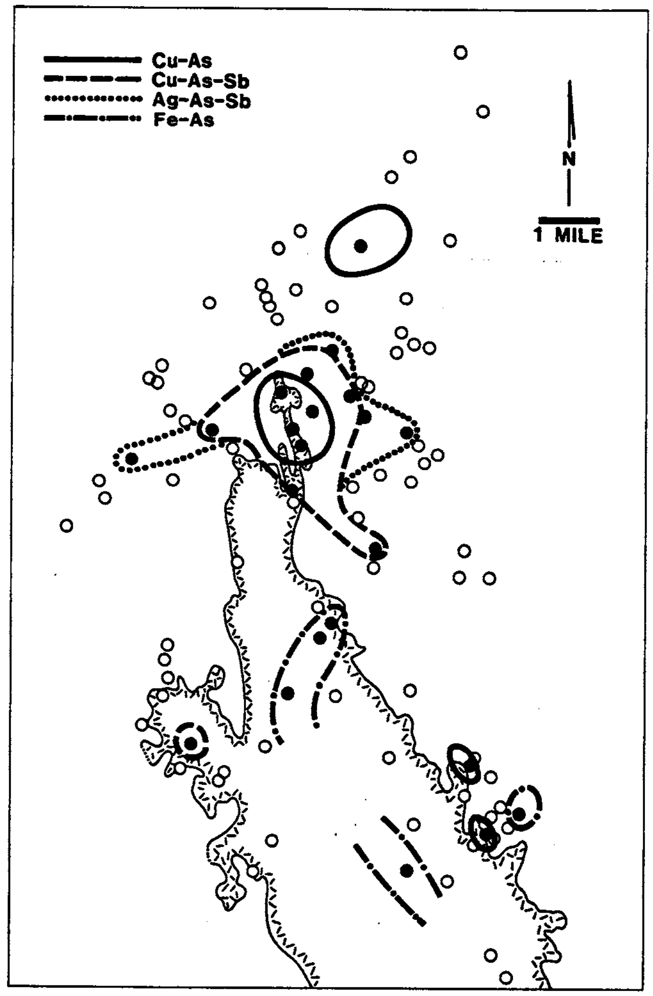

Figure 3. Distribution of mineral deposits containing abundant As and Sb in the Patagonia Mountains. Solid circles where As-Sb are abundant, open circles where As-Sb are scarce.

although small amounts of silver sulfosalt minerals are widespread.

Molybdenum

Mo is most abundant within the southern portion of the granodiorite pluton (Fig. 4), although the largest concentrations of Mo occur in the Ventura breccia pipe and in the porphyry copper deposit under Red Mountain (Corn, 1975).

Zinc

Zn is most abundant in mineral deposits at the north end of the Patagonia Mountains where it defines a tight halo concentric to, but just outside of, the large zone of disseminated pyrite at the north end of the granodiorite pluton (Fig. 5). Zn is abundant, but not obviously zoned, at Washington Camp and is not obviously zoned around Red Mountain.

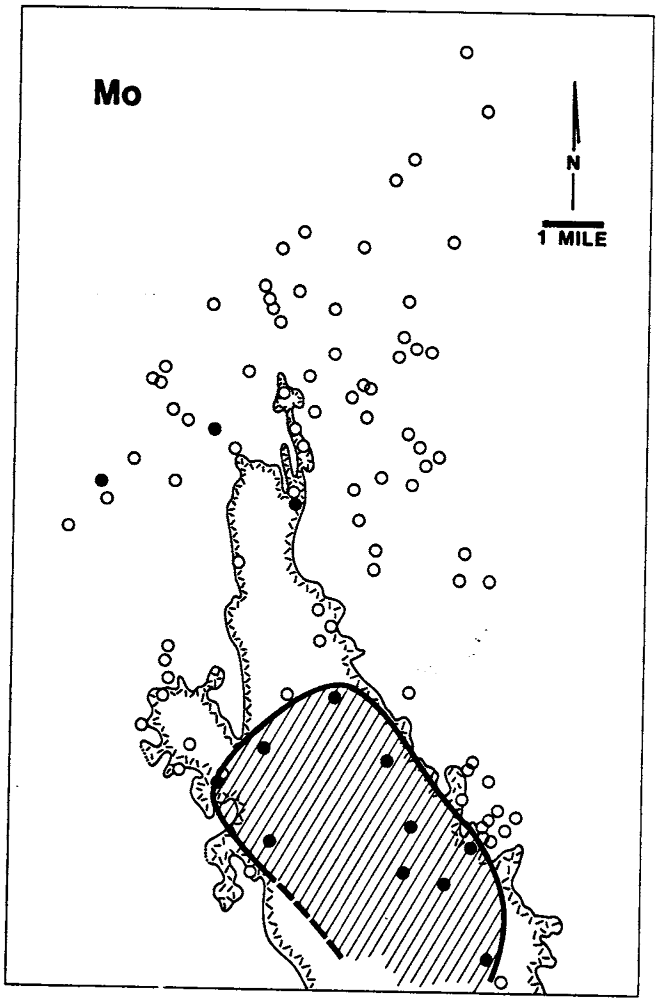

Figure 4. Distribution of mineral deposits containing abundant Mo in the Patagonia Mountains. Solid circles where Mo is abundant, open circles where Mo is scarce.

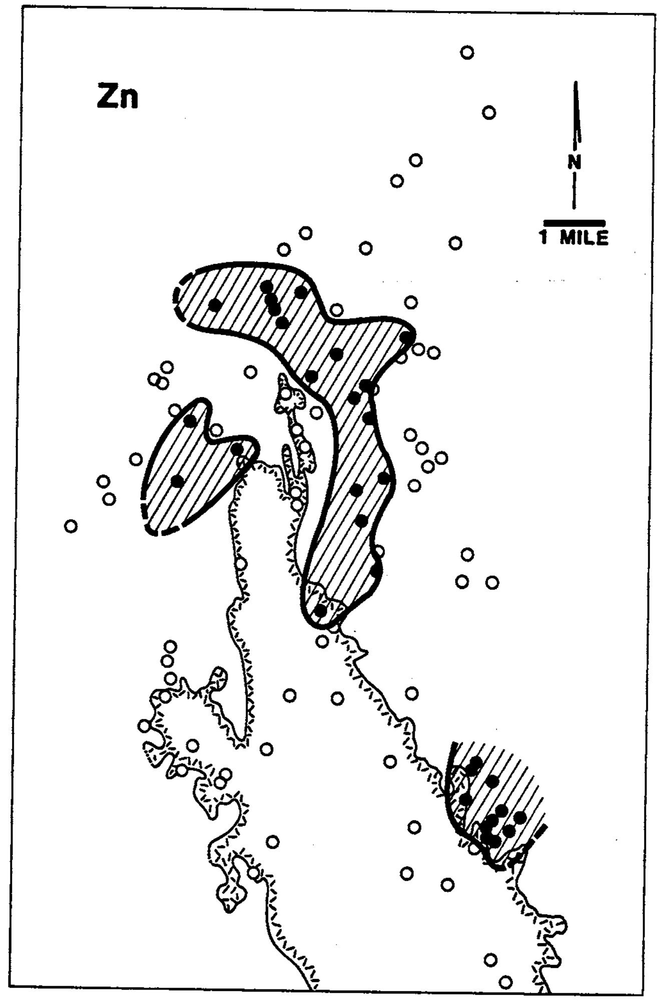

Figure 5. Distribution of mineral deposits containing abundant Zn in the Patagonia Mountains. Solid circles where Zn is abundant, open circles where Zn is scarce.

Lead

Pb is widespread at the north end of the Patagonia Mountains where it forms crude doughnut patterns which envelope the pyritic zones at the north end of the granodiorite pluton and Red Mountain (Fig. 6). The Pb zone overlies, but is much more extensive than, the Zn zone.

Silver

Ag occurs in a diverse suite of sulfides, sulfosalts, and hypogene oxides which are widespread at the north end of the Patagonia Mountains (Fig. 7). Although Ag is not known to be common as a component of galena, the Ag zone is very similar in size and position to the Pb zone and surrounds the two large pyritic zones centered on the Sunnyside mine and Red Mountain.

Manganese

Mn is present in alabandite and a number of hypogene oxide species. It forms two small, well-developed zones in wall rocks east and west of the north end of the granodiorite pluton mostly outside the Zn zones (Fig. 8). The absence of Mn north of the granodiorite pluton, an area where Pb, Zn, and Ag are abundant, may result from an overlapping of the two hydrothermal regimes centered on the Sunnyside mine and Red Mountain and imposition of a hypogene environment not conducive to deposition of Mn.

Other Metals

Ba is erratically present in several deposits in the Ag zone at the north end of the range. F and B are locally present in areas of well-developed advanced argillic alteration, but are not particularly abundant in specific mineral deposits. Chaffee et al (1981) report several areas containing anomalously high Te in stream sediments, which they suggest is derived from disseminated pyrite. They also record anomalous Au in stream sediments, although Au is exceedingly rare in the Patagonia Mountains. Various other metals such as Bi, W, and U are, like Au,

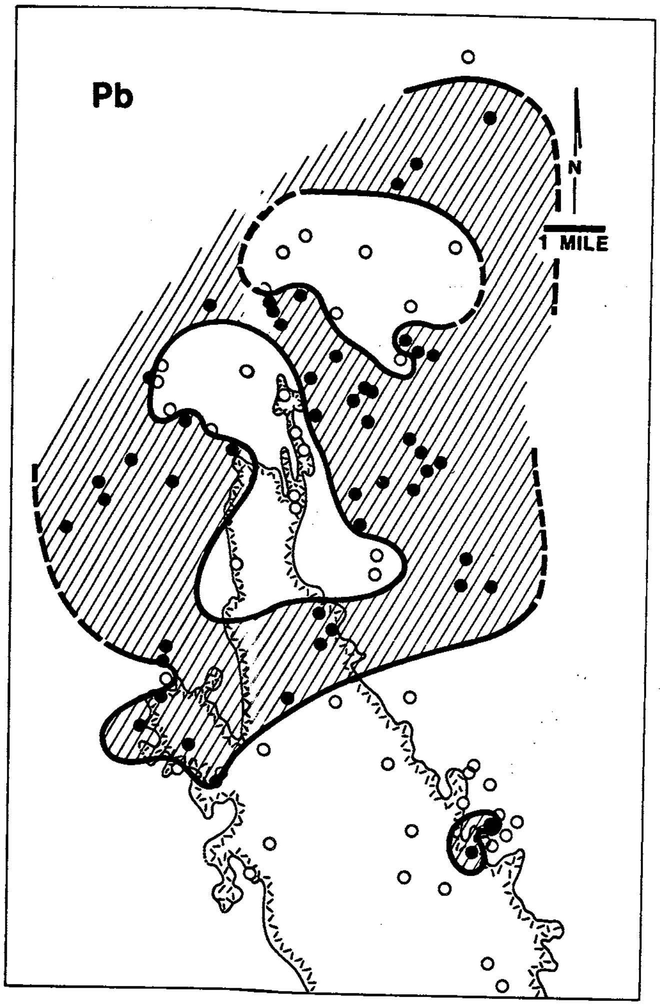

Figure 6. Distribution of mineral deposits containing abundant Pb in the Patagonia Mountains. Solid circles where Pb is abundant, open circles where Pb is scarce.

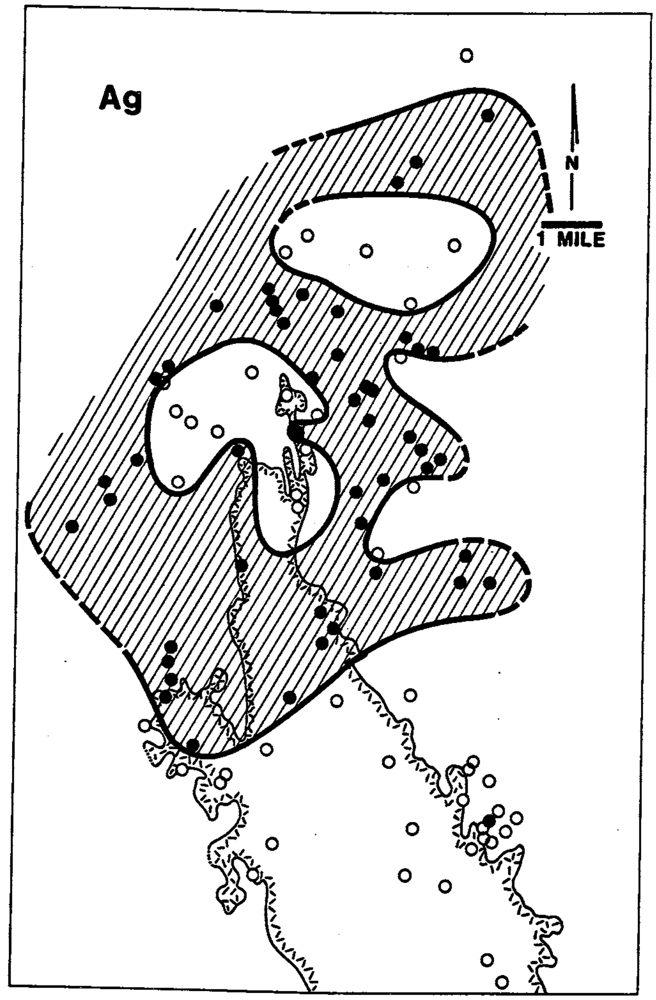

Figure 7. Distribution of mineral deposits containing abundant Ag in the Patagonia Mountains. Solid circles where Ag is abundant, open circles where Ag is scarce.

present as rare curiosities.

Discussion of Individual Metal Zoning

Cu, Mo, and As as arsenopyrite are most abundant in mineral deposits in or close to the granodiorite pluton. Mineral deposits in which As, Sb, Zn, Pb, Ag, and Mn are abundant form zones successively outward from the center of the two areas of disseminated pyrite at the Sunnyside mine and Red Mountain, but are not particularly abundant or well zoned in the southern portion of the Patagonia Mountains. The obvious conclusion that has some exploration significance is that the hydrothermal fluids which formed the zones of alteration and disseminated pyrite also carried abundant metals. In addition, the shape of the various metal zones suggests that the hydrothermal fluids moved radially outward from the centers of these zones of alteration.

It was suggested earlier that the north end of the Patagonia Mountains was less deeply eroded than the south end. The greater abundance of mineral deposits with more metal at the north end of the range suggests that greater volumes of metal were deposited in areas near the top of the granodiorite pluton rather than in areas deep within it.

Zoning of Metal Ratios

Metal ratios are plotted for those deposits on Figure 1 where assay data are available to provide additional insight into the controls of metal deposition. Many of the analyses used in this discussion were compiled from sources over 50 years old and represent sample material of imprecisely known mineralogy from mine workings which are no longer accessible. The extent to which these numbers accurately represent relative metal abundances at a particular deposit may therefore be questioned, although they appear sufficient to reveal certain district-wide relationships.

Copper/Silver

Cu/Ag decreases outward from the center of the granodiorite pluton through about 4 orders of magni-

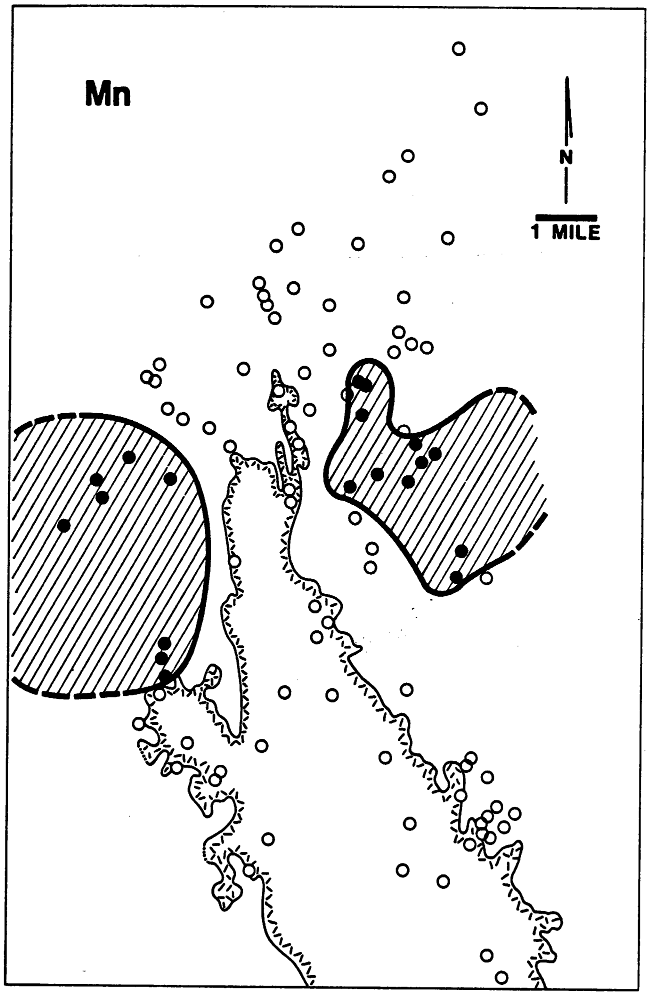

Figure 8. Distribution of mineral deposits containing abundant Mn in the Patagonia Mountains. Solid circles where Mn is abundant, open circles where Mn is scarce.

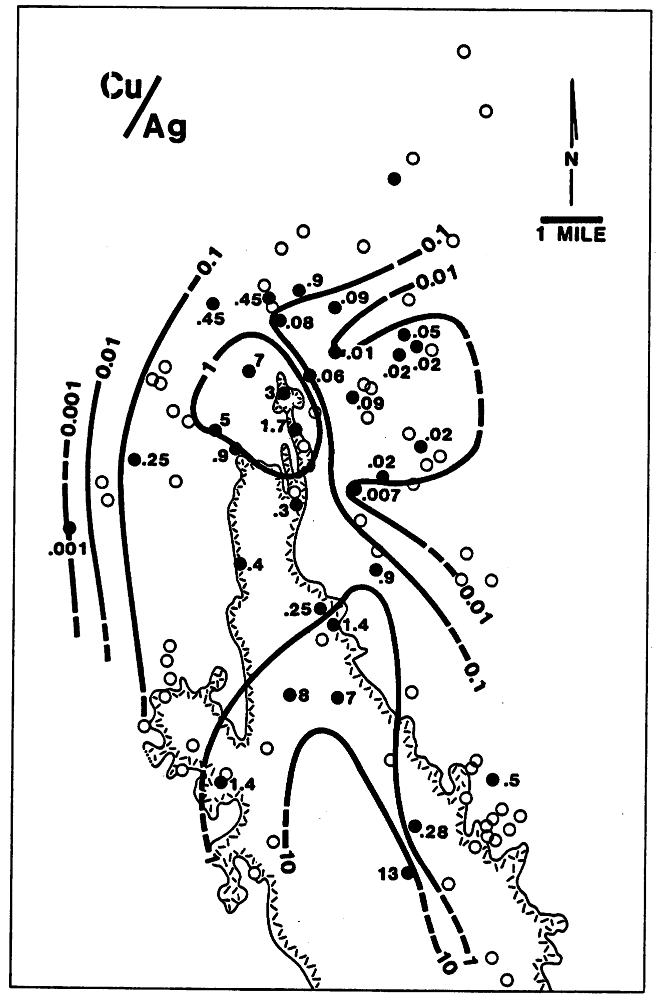

Figure 9. Cu/Ag in mineral deposits in the Patagonia Mountains expressed as % Cu/oz. Ag. Solid circles where data are available, open circles mean no data.

tude from 13 to 0.001, as shown on Figure 9. The metal ratio contours generally follow the shape of the granodiorite with an eastward bend toward Red Mountain, although this pattern is somewhat distorted between the north end of the granodiorite pluton and the Hardshell mine. The eastward bulge in the 0.01 Cu/Ag contour in the Hardshell area coincides with a well-developed N45°W striking fissure system which, because of greater permeability, may have carried equivalent hydrothermal environments farther from the zoning center at the Sunnyside mine than was possible in less fractured rocks. The inference is that hydrothermal fluid flow in the Sunnyside-Hardshell area was generally easterly or southeasterly as was previously indicated by data from individual metal zones. Similar arguments regarding the flow direction of hydrothermal fluids were advanced by Goodell and Petersen (1974) to explain metal ratio patterns at Julcani, Peru.

Figure 10 plots Cu/Ag against distance from the center of the granodiorite pluton and illustrates the relatively uniform decrease in values away from the granodiorite. This uniform metal ratio gradient suggests that the granodiorite contact has no effect on metal ratios in that there is no offset of data where the points cross the contact. In addition, Figure 10 indicates that rock type has no significant effect on Cu/Ag when viewed on a district scale. Cu/Ag in limestone replacement deposits falls along the trend defined by other mineral deposits which occur in a variety of non-carbonate rocks. It is well known that rock type, particularly carbonate rocks, may strongly influence the amount of metal deposited and that metal ratios in individual mineral deposits may vary significantly; however, the variation in Cu/Ag exceeds by orders of magnitude any differences attributable to variations in rock chemistry. Cu/Ag also appears to be largely independent of pressure, as qualitatively interpreted from depth of burial, because deposits from the north end range fall along the same trend in Figure 10 as deposits from the south end of the range. Pressure may influence north-south mineral zoning, but has no visible effect on Cu/Ag which appears to vary in an east-west rather than a north-south direction. The only remaining factor which may have varied significantly

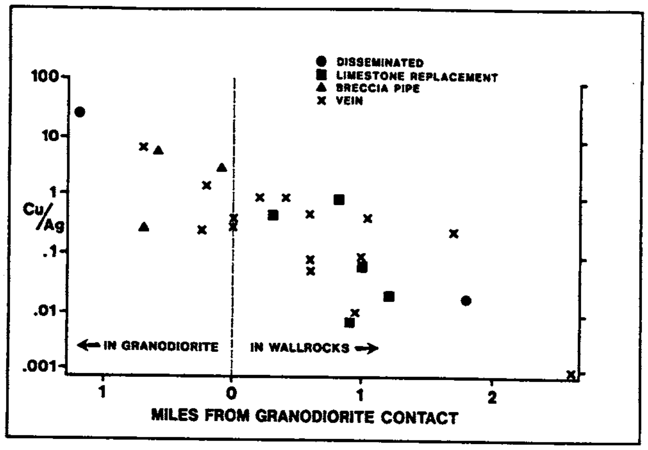

Figure 10. Relationship of Cu/Ag to distance from granodiorite contact. Represents all deposits for which data are available on Figure 9. Separate plots show no differences for deposits at north and south ends of Patagonia Mountains.

on a district-wide basis and which has been experimentally demonstrated to exert a significant impact on metal solubilities is temperature. The suggestion is made here that Cu/Ag contours are parallel to isothermal contours which existed at the time of ore deposition and this suggestion will be discussed further below.

Lead/Zinc

Contours of Pb/Zn on Figure 11 closely parallel the strike of the granodiorite pluton and appear symmetrically distributed about its eastern contact. Figure 12 shows that Pb/Zn is uninfluenced by the granodiorite contact and is not related to specific rock types. In sharp contrast to Cu/Ag, Pb/Zn is essentially constant within about 1 mile of the granodiorite contact. The behavior of Pb and Zn appears consistent with data in Hemley et al (1967) who showed that solubilities of Pb and Zn are nearly identical from 300-500°C in an alteration-buffered system. In addition, their data showed that temperature variations of 100°C can have order-of-magnitude effects on metal solubilities, an observation which may support the inference made earlier about the importance of temperature on metal ratios--which are a measure of relative solubilities.

Copper/Lead

Cu/Pb varies through roughly four orders of magnitude (Fig. 13). The axis of these contours tends to be symmetrical about the east contact of the granodiorite pluton, similar to Pb/Zn with a possible second center of symmetry around Red Mountain. In other aspects Cu/Pb appears similar to Cu/Ag.

Lead/Silver

Pb/Ag differs from other ratios in that values pass through weak maxima east and west of the granodiorite pluton (Fig. 14). Data previously derived from other zoning patterns, in addition to unlike mineral assemblages on each side of the maxima, make it clear that hydrothermal fluids did not rise and

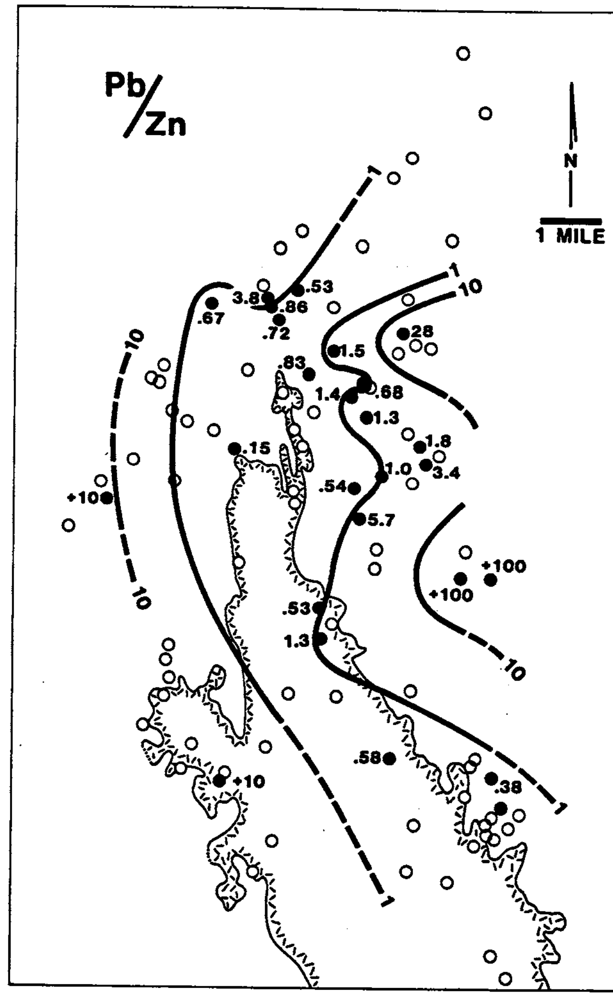

Figure 11. Pb/Zn in mineral deposits in the Patagonia Mountains. Solid circles where data are available, open circles mean no data.

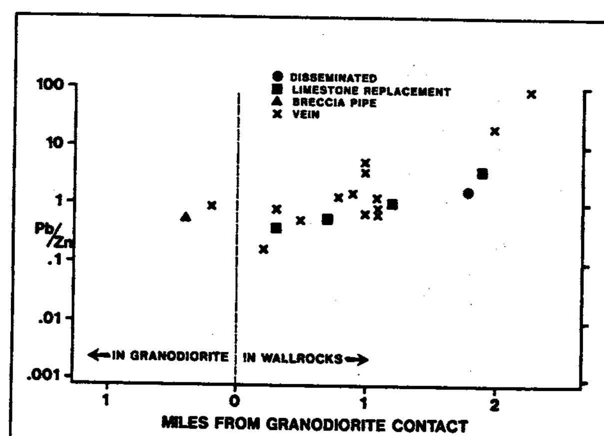

Figure 12. Relationship of Pb/Zn to distance from granodiorite contact. Represents all deposits for which data are available on Figure 11. Separate plots show no difference for deposits at north and south ends of Patagonia Mountains.

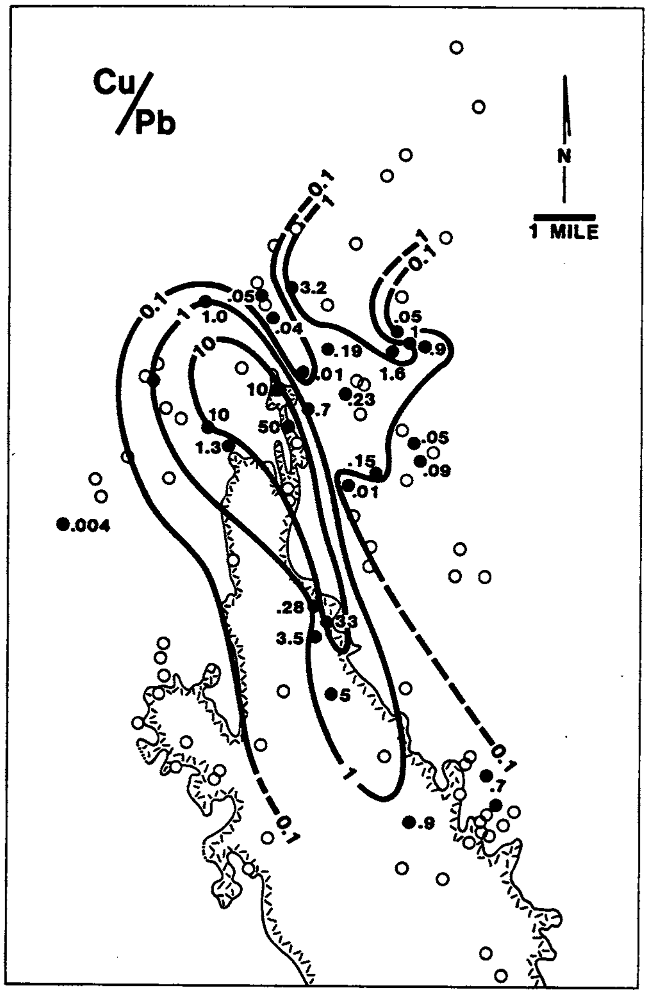

Figure 13. Cu/Pb in mineral deposits in the Patagonia Mountains. Solid circles where data are available, open circles mean no data.

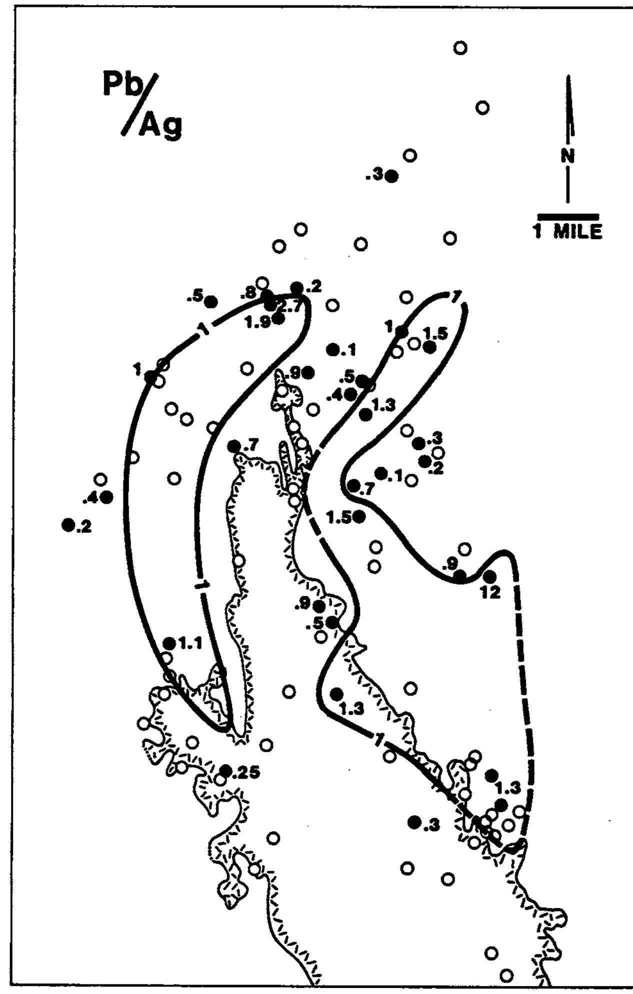

Figure 14. Pb/Ag in mineral deposits in the Patagonia Mountains. Solid circles where data are available, open circles mean no data.

spread laterally from the axis of high Pb/Ag values. A similar pattern was found for Ag/Pb in the Herminia mine at Julcani by Goodell and Petersen (1974) where it coincided with a zone of rich silver mineralization.

<u>Lead/Zinc</u>
<u>Copper/Silver</u>

Values of this ratio are plotted and contoured on Figure 15. To the extent data are available, this ratio illustrates the uniformly varying contours which rather nicely reflect the shape of the granodiorite pluton and which also tend to emphasize symmetry of the contour pattern about the east contact of the granodiorite. The easterly bend in the contours toward Red Mountain is typical of all the metal ratio zoning patterns.

Discussion of Metal Ratio Zoning

The current trend in ore deposit research is to focus in great detail on each of the multitude of individual processes in the hydrothermal fluid which can influence ore deposition. Nevertheless, the phenomenally complex interplay through time of numerous physical and chemical variables which cause ore deposition in hydrothermal systems invariably produces remarkably consistent zoning patterns, suggesting that fundamental controls of this zoning are both simple and similar. The complexities in a single mineral deposit are magnified many times in the Patagonia Mountains when the geographically and geologically diverse suite of 95 mineral deposits are viewed as a single group, but the relatively simple metal ratio zoning patterns revealed in this study seem to require a relatively simple explanation.

Beane and Titley (1981) summarize three theories which have been advanced to explain alteration zoning in porphyry copper systems, an environment which most closely resembles the mineral deposits in the Patagonia Mountains. These are 1) temperature variations, 2) irreversible reactions between the hydrothermal fluid and the wall rock, and 3) mixing or simple encroachment of fluids from different sources. Depth of burial (pressure) is less accepted, but in any case also merits some comment. Since specific sulfide

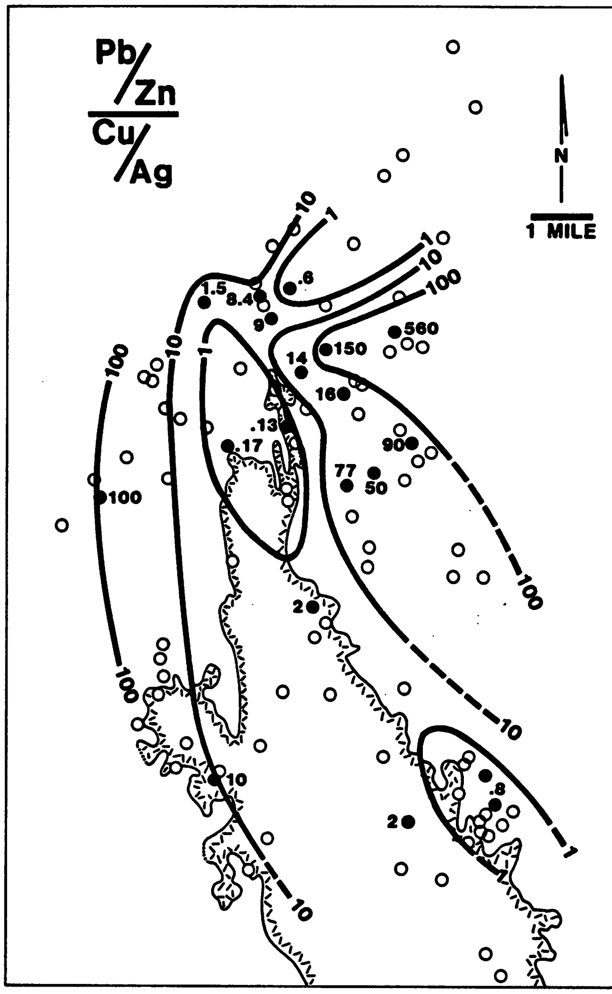

Figure 15. $\frac{Pb/Zn}{Cu/Ag}$ in mineral deposits in the Patagonia Mountains. Solid circles where data are available, open circles mean no data.

minerals always occur with specific alteration assemblages, it is logical to assume that the processes which cause alteration zoning also cause or catalyze reactions which cause metal deposition.

Contours of metal ratios on a district scale are parallel to the long axis of the granodiorite pluton. The contours extend without offset through a highly variable suite of lithologies which indicate that the influence of rock chemistry on the relative amounts of Cu, Pb, Zn, and Ag deposited was generally minor compared to variations on a district scale. This observation receives support from work by Lehman (1980) who found that variations between high and low values of Cu/Ag, Pb/Zn, Pb/Ag, and Cu/Pb never exceeded a factor of 4 for different host rock lithologies or alteration assemblages. In addition, variations between high and low values of metal ratios for different orebodies at the Flux mine did not exceed 2 and for different ore types at the Hardshell mine did not exceed 17. These numbers are in sharp contrast with district variations between high and low values in the Patagonia Mountains which are for Cu/Ag-13,000, Pb/Zn-600, Pb/Ag-120, and Cu/Pb-12,000.

In addition, many of the mineral deposits in the Patagonia Mountains are veins in which there has been only limited reaction between the fluid and adjacent rocks due to a lining of the vein walls by early-formed hydrothermal minerals.

It is possible, but equally unlikely, that different metal ratios formed from fluids of different composition. There are several reservoirs for substantial volumes of compositionally different fluids including the granodiorite pluton for magmatic water, the rather diverse suite of sedimentary rocks for connate water, and meteoric water. However, given the large area involved, the large number of rock types present, and the apparent substantial variation in depth of exposure, it is unlikely that fluids of such different provenance would have been present uniformly over such a large area as the metal ratio contour patterns would suggest.

In addition, the absence of strong closures at the north <u>or</u> south end of the Patagonia Mountains suggests that depth of burial also had little effect on metal ratio zoning. Some closures are present, but they are weak and often occur at both ends of the granodiorite pluton. Closures would be anticipated at the north end of the range for As and Sb if analytical data were available and would indicate a vertical zoning with As and Sb being relatively more abundant at the north end of the range where the rocks are less deeply eroded. Vertical metal zoning is well developed in individual hydrothermal systems in the Patagonia Mountains (see, for instance, Corn, 1975), but the scale of such zoning even in a porphyry copper system the size of Red Mountain (3000-5000 ft. to encompass fully the mineralogical changes) is insignificant when viewed on a scale of the entire Patagonia Mountains.

I conclude that deposition of Cu, Pb, Zn, and Ag and formation of metal ratio contours <u>on a district scale</u> in the Patagonia Mountains would seem to be most strongly influenced by variations in temperature and it is likely that the metal ratio contours are parallel to isotherms which existed when the bulk of the metals was being deposited. Irregularities in the contour patterns probably reflect non-representative samples, vertical zoning in individual hydrothermal systems, and areas of strong permeability contrast which would have led to varying hydrothermal fluid flow rates and resulting differing convective heat transfer rates. There is no doubt that some reactions occurred between the hydrothermal fluid and the wall rocks and it is likely that some mixing of compositionally different fluids took place. It is clear that these processes can cause metal deposition, but the geological relationships suggest that these processes did not influence the district-wide distribution of metal ratios in a significant way. Cooling of a hydrothermal fluid also has a strong influence on metal solubilities and is the one phenomenon of the three mentioned which might be expected to operate most uniformly over the largest area. Barnes (1979) stated that solubilities of Fe and Cu in chloride complexes vary from adequate at 350°C to insufficient at 250°C to deposit ore grade concentrations in porphyry copper systems, given geologically reasonable volumes of hydrothermal fluid and, noting the frequency with which fluid inclusion homogenization temperatures occur in the interval 350-250°C for metal-bearing assemblages, emphasized the importance of cooling as a prominent control of ore deposition. Data discussed earlier by Hemley et al (1967) for Pb and Zn are also compatible with the importance of cooling as a primary cause of ore deposition. Any of the three causes of zoning and metal deposition described above, along with physical changes in the state of the hydrothermal fluid, may locally (in a specific mineral deposit at a specific time) control metal ratios, but the uniform behavior of metal ratio zoning on a district scale in the Patagonia Mountains, which greatly exceeds the scale of a specific mineral deposit or hydrothermal system, would seem to be explained best by variations in temperature.

The axes of several metal ratio contour patterns coincide with the eastern contact of the granodiorite pluton. If the eastern contact is the axis of the thermal anomaly, it would suggest either that the granodiorite is present at shallow depths under the eastern portion of the range or that the east side of the granodiorite may follow an important structural feature which controlled the movement of hydrothermal fluids and resulting convective distribution of heat. Although data are sparse, the tendency of the contours to turn northeasterly toward and, in some cases, to envelope Red Mountain suggests that a large Laramide intrusion is also present at depth in this area.

THE POSITION OF PRECIOUS METALS

Silver is the only important precious metal in the Patagonia Mountains. The absolute abundance of Ag within a single mineral deposit may vary widely due to a multitude of factors, but its total abundance in a deposit relative to other metals appears to be controlled largely by the thermal patterns established after the granodiorite pluton was emplaced.

Hardshell and Mowry, the two most prominent Ag deposits, both lie about 2 miles east of the granodiorite pluton. Data are not available to evaluate zoning patterns east of these deposits, but they may lie in a Pb/Ag low which would indicate a zone of heavy precipitation ("dumping") of Ag relative to Pb and perhaps to other metals and would be a favorable area to prospect, assuming the geologic environment was also conducive to the formation of large absolute amounts of Ag.

The position of Ag in other porphyry copper environments will likely resemble zoning patterns in the Patagonia Mountains. At Butte, Montana (Meyer et al, 1968) ore rich in Ag was mined in the Peripheral Zone which surrounded an Intermediate Zone containing Zn and Cu, and a Central Zone dominated by Cu. Mn is abundant in the Ag ores, both at Butte and in the Patagonia Mountains. It is tempting to suggest that the very regular and symmetrical district zoning boundaries at Butte were strongly influenced by simple cooling.

The distribution of Au cannot be determined from available data. Chaffee et al (1981) found that areas of anomalous Au and Ag in stream sediment showed extensive overlap, but their work failed to define the obvious Ag lows shown on Figure 7 which overlie the pyritic zones centered on the Sunnyside mine and Red Mountain and emphasized instead several areas where Ag and Au are present in elevated although economically insignificant amounts through large volumes of pyritic rocks. Their sediment sampling exercise does not accurately reflect the abundance of Ag (and perhaps Au) in individual mineral deposits and cannot be used to assess the relative or absolute abundance of Ag in specific mines or prospects in the Patagonia Mountains or to predict where such ores might be found.

CONCLUSIONS

An empirical review of district-scale zoning of Cu, Pb, Zn, and Ag in the Patagonia Mountains suggests that:

1) Metal ratio contours are parallel to isothermal contours established following emplacement of the granodiorite pluton;

2) Temperature variations exerted a fundamental control on the relative amount of each metal deposited such that the bulk metal content of individual mineral deposits, even those with strong internal zoning and several paragenetic stages, was inherited from the position of that deposit in the district zoning pattern;

3) Rock type and permeable structure may control the total amount of metal deposited, but their influence on the relative amount of metals deposited is minor compared to temperature.

The obvious spatial association of the mineral deposits in the Patagonia Mountains to the granodiorite pluton is clear evidence that they are of Laramide age. Although it can't be proven, it is likely that the metals are also derived from the granodiorite. Some evidence in support of this suggestion was reported by Graybeal (1973) who found that a strongly elevated Cu content existed in the granodiorite during the early stages of magmatic crystallization. The absence of metal zoning around several Jurassic plutons which cut wall rocks similar to those around the granodiorite suggests that the mere presence of a granitic intrusion is not sufficient to cause mineralization; a further requisite is that the intrusion must be metal rich.

ACKNOWLEDGEMENT

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REFERENCES

Baker, R.C., 1961, The geology and ore deposits of the southeast portion of the Patagonia Mtns., Santa Cruz County, Ariz.: Univ. of Michigan Ph.D. dissertation.

Barnes, H.L., 1979, Solubilities of ore minerals: in Geochemistry of Hydrothermal Ore Deposits, 2nd ed.; H.L. Barnes ed., New York: John Wiley and Sons, p. 404-460.

Beane, R.E., and Titley, S.R., 1981, Porphyry copper deposits. Part II. Hydrothermal alteration and mineralization: in Economic Geology, 75th Anniversary Volume; p. 214-269.

Chaffee, M.A., Hill, R.H., Sutley, S.J., and Watterson, J.R., 1981, Regional geochemical studies in the Patagonia Mtns., Santa Cruz County, Ariz.: Jour. Geochem. Explor., v. 14, p. 135-153.

Corn, R.M., 1975, Alteration-mineralization zoning, Red Mtn., Ariz.: Econ. Geol., v. 70, p. 1437-1447.

Goodell, P.C., and Petersen, U., 1974, Julcani mining district, Peru: A study of metal ratios: Econ. Geol., v. 69, p. 347-361.

Graybeal, F.T., 1973, Copper, manganese, and zinc in coexisting mafic minerals from Laramide intrusive rocks in Arizona: Econ. Geol., v. 68, p. 785-798.

_______, 1975, Metal zoning in the Patagonia Mtns., Ariz. (abs): Symposium on Base and Precious Metal Districts of New Mexico and Arizona: New Mexico Geol. Soc. and Ariz. Geol. Soc., Silver City, N. Mexico, p. 14-15.

Hemley, J.J., Meyer, C., Hodgson, C.J., and Thatcher, A.B., 1967, Sulfide solubilities in alteration-controlled systems: Science, v. 158, p. 1580-1582.

Koutz, F.R., 1983, The Hardshell silver, base-metal, manganese oxide deposit, Patagonia Mtns., Santa Cruz County, Ariz.: A field trip guide: Ariz. Geol. Soc. Digest 15, in press.

Lehman, N.E., 1980, Pyrometasomatic deposits of the Washington Camp-Duquesne District, Santa Cruz County, Ariz.: Mining Engineering, p. 183-188.

Meyer, C., Shea, E.P., Goddard, C.C., Jr., et al., 1968, Ore deposits at Butte, Montana, in Ridge, J.D., ed., Ore Deposits of the United States, 1933-1967 (Graton-Sales Vol.): New York, Am. Inst. Min. Met. Pet. Eng., p. 1373-1416.

Northern Miner Press, 1970, Iso Mines Ltd., in Fielder, F.M., ed., Canadian Mines Handbook 1970-1971: Toronto, Northern Miner Press Ltd., p. 188.

Schrader, F.C., 1915, Mineral deposits of the Santa Rita and Patagonia Mtns., Ariz. with contributions by J.M.Hill: U.S. Geol. Sur. Bull. 582.

Simons, F.S., 1972, Mesozoic stratigraphy of the Patagonia Mtns. and adjoining areas, Santa Cruz County, Ariz.: U.S. Geol. Sur. Prof. Paper 658-E, 23 p.

_______, 1974, Geologic map and sections of the Nogales and Lochiel quadrangles, Santa Cruz County, Ariz.: U.S. Geol. Sur. Misc. Geol. Inv. Map I-762: 1 pl., 9 p.

NICOR MINERAL VENTURES

Prospect and Submittal Report

Date: October 26, 1984

Property Name: Ivanhoe Altered Area

County, State: Santa Cruz, Arizona

Date Examined: 10/25 By: G.A. Parkison

Reply and Date:

Township: 21,22S

Range: R15E

Section: 34, 1, 2

Quadrangle Name: Mt. Wrightson 15'

AMS Sheet: Nogales

Summary, Conclusions, Actions Recommended: Contrary to USGS work area does not appear to have Au-Ag associated with the altered granitic rocks. No further work.

Location and Accessibility: About 3 miles NW of Patagonia. Follow F.S. road 144 towards Ivanhoe Mine. Other F.S. road goes past house to well, dam.

Owners and Intermediaries, Address, Phone, Zip: Old claim by Urania (1977) and Kerr-McGee (1972) Property probably open at present.

Property Description, Status: Ivanhoe mine is past Au-Ag producer, consists of ~5 patented claims. Long inactive. Presently inaccessible to vehicle.

Terms:

Previous Exploration and Production: Unknown, but probably small production, workings of shaft and 250' deep, drifts total maybe 2000'.

General Geology: Area of Squaw Gulch granite generally overlain by E-dipping tertiary volcaniclastics. Cut by prominent NNW trending faults.

Geology of Prospect*: Approx. 1 sq. mi. area of alteration within Squaw Gulch granite is supposedly anomalous in Au, Pb, Zn, Mo with peripheral Au, Ag. Alteration cut by younger E-W trending qtz veins. Preference for manzanita trees on most altered ground.

Mineralization* (Primary and Secondary): Alteration ranges from none thru fairly narrow propylitic zone to argillic and phyllic. Most common is phyllic or qtz - sericite. Center part of area is tensely fractured with abund FeOx along fractures. Much FeOx after pyrite. Qtz veins generally 1" or so, few veins to ~2' thick, vertical. Kerr-McGee drilled one hole by tank.

Geochem Results: See sheet. Nothing remarkable.

Exploration Recommended: None, unless looking for porphyry copper.

Attachments:

References: USGS B. 582, USGS B. 1356; Map I-614; USGS pp 575-0, p. 176-182

* Attach geologic map, sketch or otherwise, including examiner's observations with emphasis on mineralization and alteration and their relationships to other geological features. Other desirable attachments: Location map, property map, sample results, etc.

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REPORT OF ANALYSIS

JOB NO. UGH 033
November 7, 1984
A 398 THRU A 405

NICOR MINERAL VENTURES
2341 So. Friebus, Suite 12
Tucson, Arizona 85713

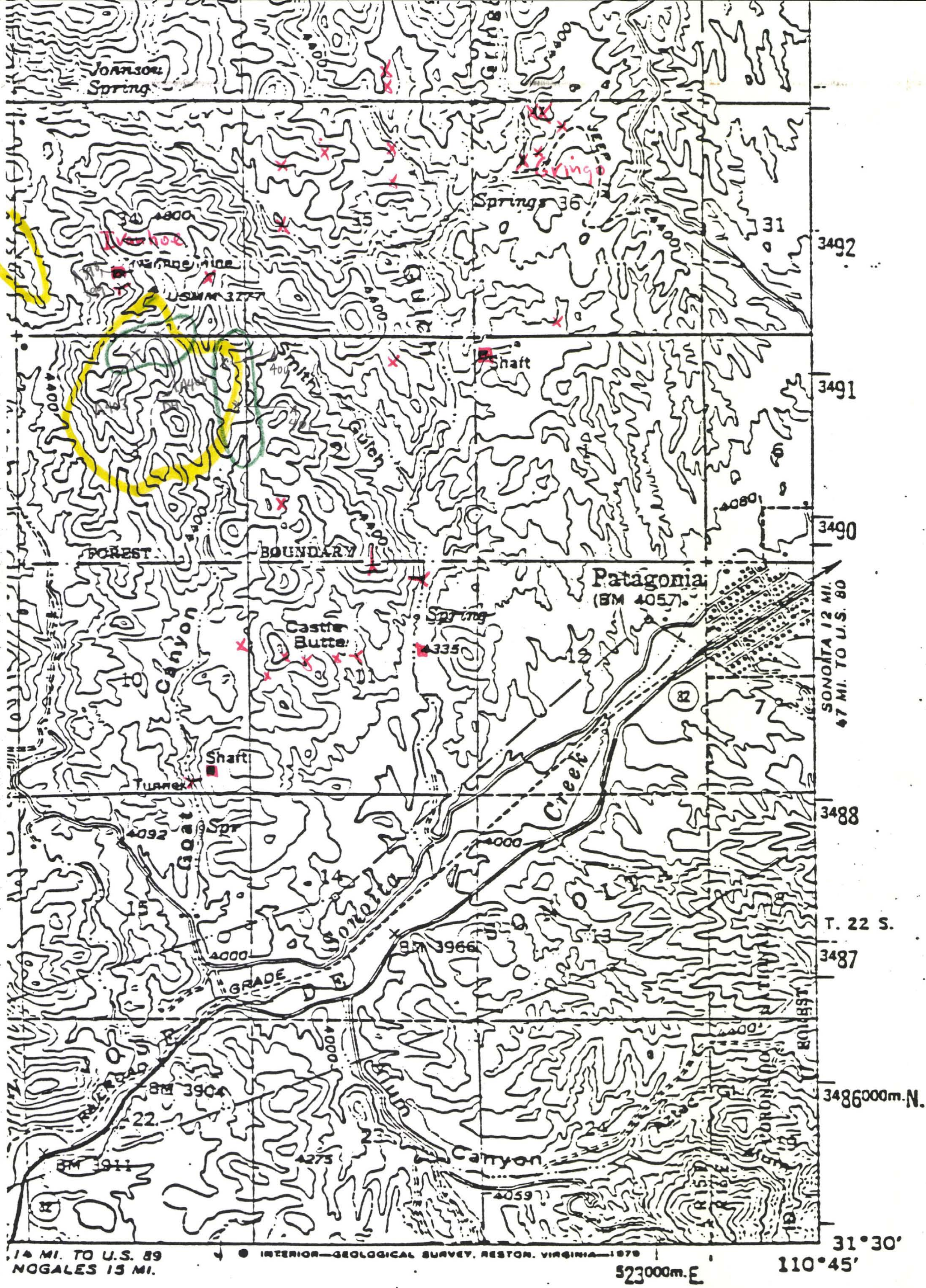
Analysis of 8 Rock Samples

ITEM	SAMPLE NO.	Au (ppm)	Ag (ppm)	Cu (ppm)	Pb (ppm)	
1	A 398	<.02	7.2	1150.	220.	- rhyo. dike
2	A 399	<.02	49.0	265.	990.	- qtz vein - Ivanhoe
3	A 400	<.02	1.8	25.	45.	- altered intru
4	A 401	<.02	.6	45.	75.	- altered intru
5	A 402	<.02	.6	40.	90.	- altered intru
6	A 403	.09	1.4	25.	5.	- altered intru
7	A 404	<.02	<.2	20.	35.	- qtz veins
8	A 405	<.02	<.2	10.	35.	- altered intru

Charles E. Thompson
Arizona Registered Assayer No. 9427

William L. Lehmbeck
Arizona Registered Assayer No. 9425

James A. Martin
Arizona Registered Assayer No. 11122

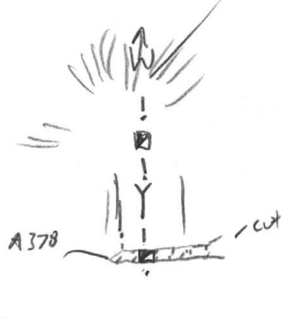


ROAD CLASSIFICATION

Heavy-duty ———— Light-duty ————

(LOCHIEL 3846 I)

A398 - random chip across ~5' wide brecc. white rhyo. dike, some slight silic. and FeOx
dike cuts qtz veins



A399 - grab of qtz on dump. - gray, white, mostly massive, sugary, up to ~4% py.
vein trends E-W
- shaft ~ 6x6' - deep
dumps ~ 6,000 tons
- qtz veins erratic, mostly <2' thk.

A400 - random chip from outcrop, prop-argill altered intru. occas. EW qtz vein

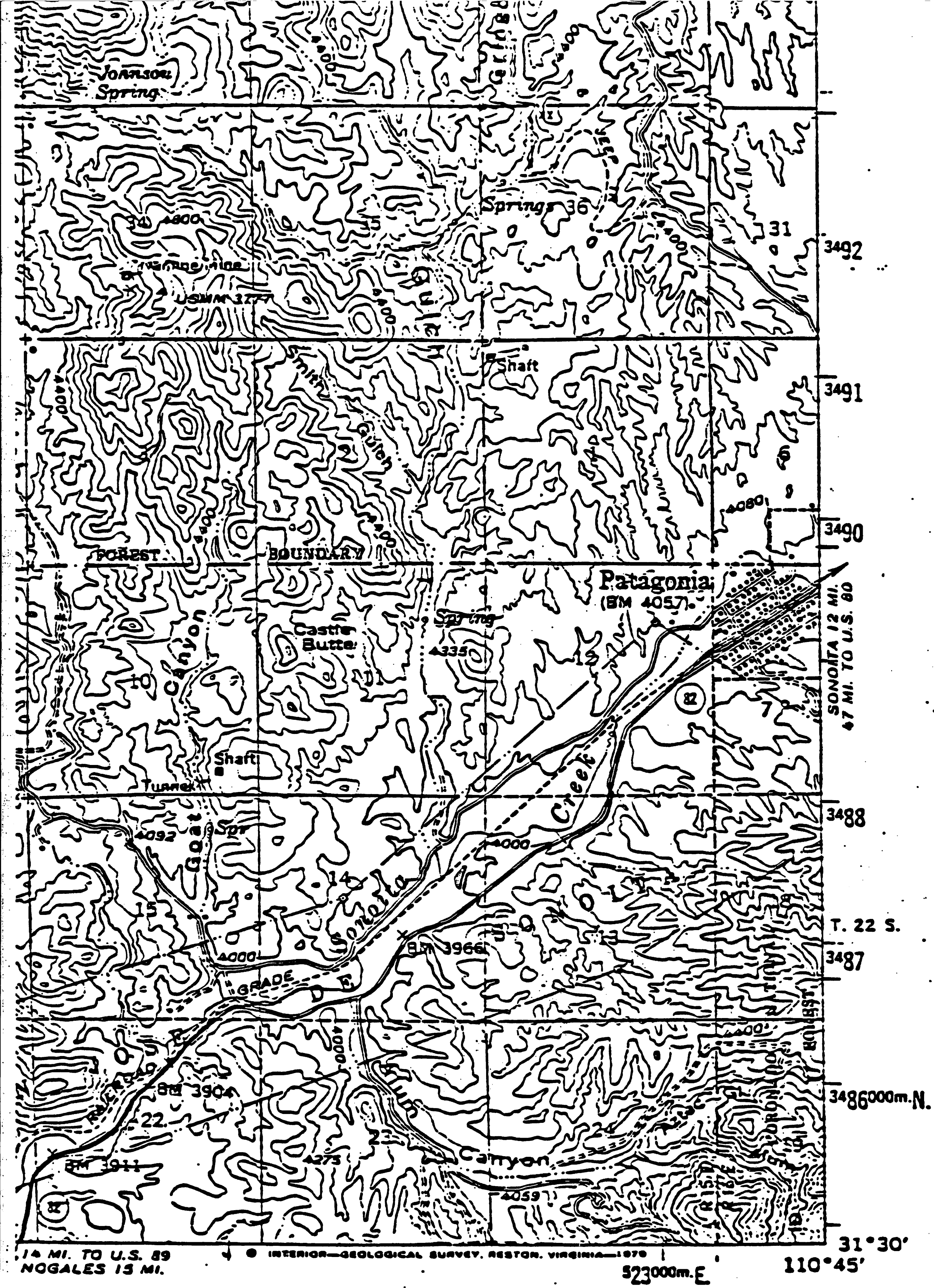
A401 - same as A400

A402 - chip along stream - phyllic alter. intr - qtz-sericite-py-FeOx, occas qtz vein.

A403 - grab from stream - same as A402

A404 - select grab of qtz veins ~ 0.5-1" qtz-FeOx veins over ~25' interval. - small pit - argillic alter. intr. wallrx.

A405 - grab along stream of outcrop + cobbles - all altered intru, some qtz vein mat.



ROAD CLASSIFICATION

Heavy-duty ———— Light-duty ————

(LOCHIEL) 3846 I