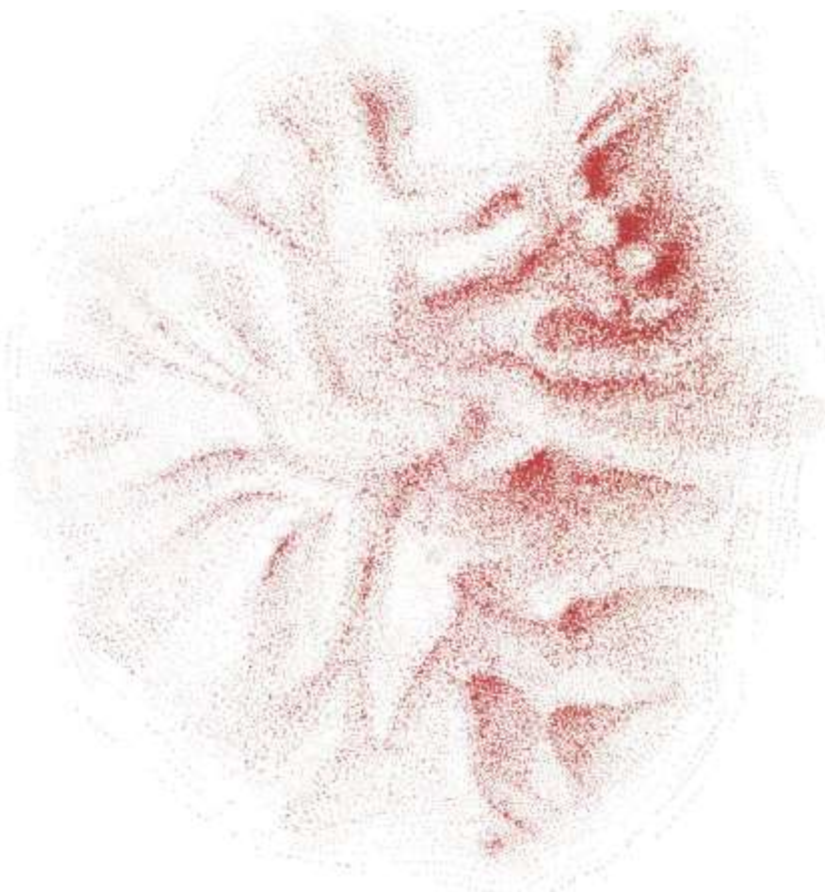
Trace Base Metals, Petrography, And Alteration Tres Hermanas Stock, Luna County, New Mexico

by P Doraibabu and Paul Dean Proctor



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University of Missouri—Rolla

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ABSTRACT

Zinc, lead and minor copper-bearing replacement and vein-type deposits occur in Paleozoic sedimentary rocks and Tertiary volcanic rocks adjoining the Tres Hermanas granite-quartz monzonite stock, Luna County, New Mexico. In an attempt to prove or disprove a possible genetic relationship between these mineral deposits and the stock, 99 grid samples from the stock and 22 soil samples from a re-entrant alluvial valley were analyzed for trace contents of zinc, lead and copper. Thirty-four grid rock samples were petrographically studied and modal analyses calculated and alteration products estimated. Trace metal zinc, lead and copper anomalies are spatially related to each other. Zinc and lead anomalies are almost congruent with less agreement with low-level copper anomalies. A close spatial relationship exists between anomalous trace concentrations of zinclead-copper in the stock and external hydrothermal deposits in Paleozoic sedimentary rocks and Tertiary volcanics. The ratios of highest zinc, lead and copper concentrations in the anomalies of the stock show general agreement to the ratios of production of these same metals from the adjacent mineral deposits. Alteration appears to be a general requisite for trace metal anomalies within the stock. A relationship also appears to exist between certain primary petrographic textures and the anomalies of zinc, lead and copper suggesting a possible late magmatic or deuteric origin for at least one stage of the development of the anomalies. Yet, in combination with rock alteration, a two-phase or continuous-phase origin of the anomalies appears likely. The isolated character of the trace metal anomalies, their patterns within the stock, the decrease in, the magnitude of the anomalies near the stock contacts marginal to mineralized zones, and primary petrographic textures and alteration features associated with the anomalies, suggest that the source of the geochemical anomalies and the mineral deposits was the stock. In the alluvial area north of the stock, geochemical anomalies of zinc, lead and copper suggest possible nearby sources of metal in the bedrock.

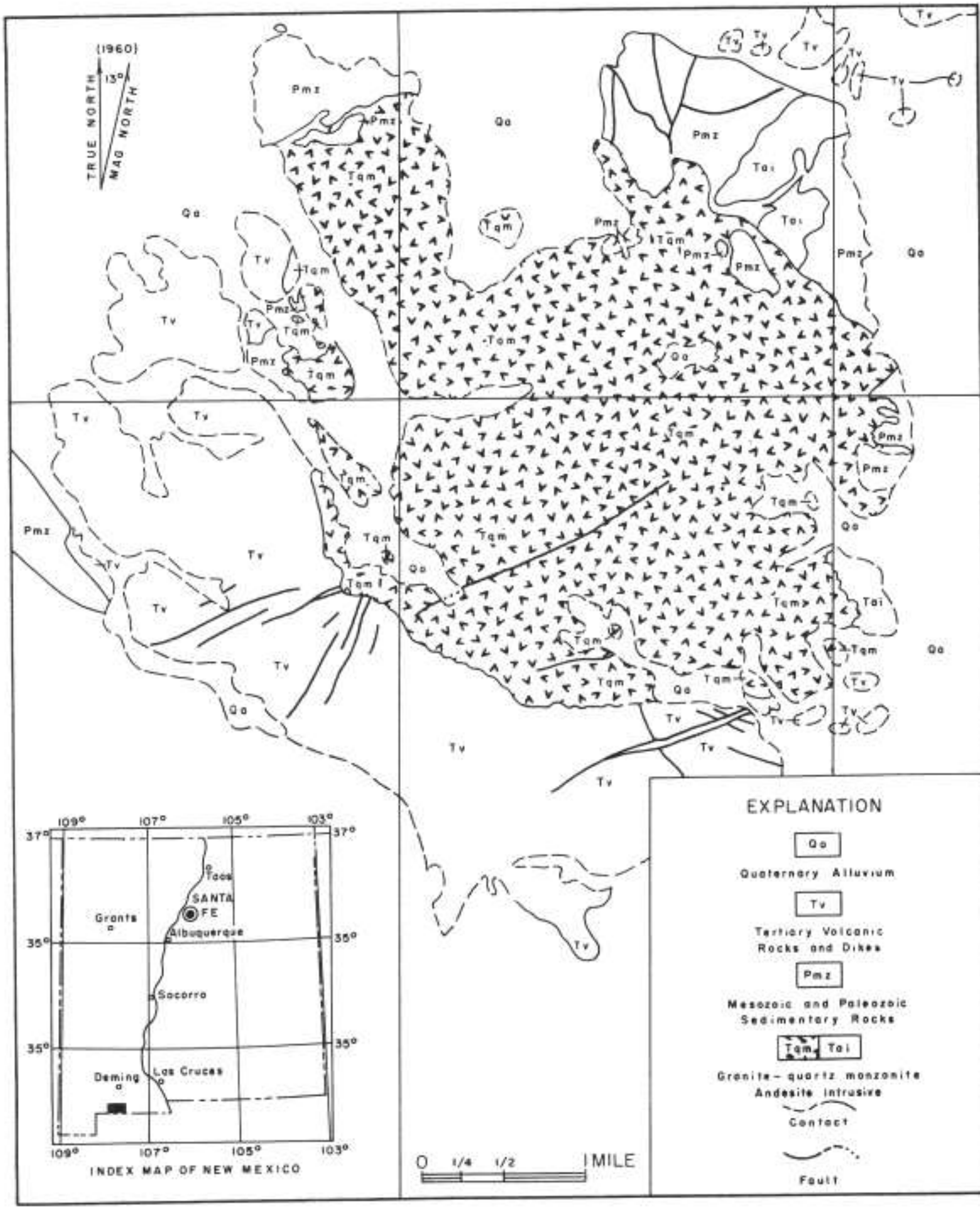

FIGURE 1—*Index map of Tres Hermanas Mountains.*

INTRODUCTION

Purpose and Scope

The exposed Tertiary granite-quartz monzonite stock, comprising almost half of the Tres Hermanas Mountains, and some of the alluvial area to the north, was studied in respect to its content of trace elements of copper, lead and zinc, and its petrography and alteration. Purpose of the study was to determine the spatial inter-relationships of these features within the stock and to the known metallic mineralization around the stock. Discussing in detail the geology, ore microscopy, mineralogy of ore bodies, and ore bodies per se was not the purpose of this study. These data are already published. The Tres Hermanas mining district has produced moderate amounts of lead and zinc and minor silver, gold and copper (Griswold, 1961).

The current study suggests that certain trace concentrations of lead, zinc and copper, and rock alteration types within the stock may relate to known and possible zones of mineralization around the periphery of the body. The mineral composition of the granite-quartz monzonite porphyry, grain size, and isolated hydrothermal alteration zones are related to the trace element trends noted. Confirmation of such relationships in other productive stocks could yield an exploration tool that would be most useful in identifying productive stocks and predicting general locations of possible mineralized areas about them.

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Location

The area studied includes the Tres Hermanas mining district in the Tres Hermanas Mountains, Luna County, New Mexico, a few miles northwest of Columbus (fig. 1). Accessibility is by five roads which branch off state highway 11 between Deming and Columbus, New Mexico. The Southern Pacific Transportation Company operates an E-W line passing through Deming.

Physiography and Climate

The area is in the Mexican Highlands section of the Basin and Range Province. Bolson plains form the physiographic feature of major extent in the area. These slope gently from an elevation of about 4200 feet and descend to 3960 feet south of Arena. The Tres Hermanas Mountains consist mainly of three connecting peaks (fig. 2): North Peak (5802 ft), Middle Peak (5786 ft), and South Peak (5674 ft) with Chloride Peak (5604 ft) to the west (fig. 3). Maximum relief is about 1800 feet. Drainage is provided by the many dry washes which radiate from the mountainous area. The chief washes are: Crump Draw on the east, Mary Lee Draw on the southeast, Lonesome Cabin and Manning Canyon Draws of the west, and the north alluvial area on the north of the mountains.

The climate of the area (table 1) is typical of the extreme southwestern part of the United States, hot summers and mild winters. Nearby Columbus frequently has the highest daily recorded temperature in the state, both winter and summer.

TABLE 1—*Climatological data for Luna County* (from Climate and Man, U. S. Dept. Agriculture, 1941, p. 1013)

		Temperature (°F)				Precipitation (in)		
Station	Altitude (ft)	Jan. avg.	July avg.	Maximum	Minimum	Wettest month	Dryest month	Annual avg.
Columbus	4,058	42.5	82.5	111	-6	August 2.19	April 0.24	9.59
Deming	4,336	41.6	78.8	110	-7	July 1.85	April 0.25	9.20
Gage	4,489	41.2	79.6	111	-9	July 2.05	April 0.21	9.93

The bolson plains are sparsely covered with desert grass, mesquite, creosote bush, yucca, and many varieties of cactus. Similar plants grow in the mountains. At the highest elevations, juniper and piñon appear. The land is used mainly for ranching.

Sampling Methods

The Tres Hermanas stock is a so-called productive stock. Because of its productivity and excellent rock exposures, and the results of other studies of productive stocks by Belt (1960), Shrivastava and Proctor (1962), Al-Hashimi and Brownlow (1970), Mantei, Bolter and Al-Shaieb (1970), and others, a statistical sampling of the body was implemented. The major objective was to determine if certain petrochemical relationships might be valuable in directly identifying a productive stock and related areas of mineralization about its borders.

Sample locations for the stock were predetermined on an orthogonal grid over the area. Sixty sample sites coincided with section and quarter section boundaries over the approximate 10 square miles of the stock. One hundred fifty fresh rock samples were collected. Supplemental rock samples were collected where rock alteration was observed. Here samples sites paralleled the original orthogonal grid system with individual sample distances adjusted according to the scale of the alteration. At 40 sites, 82 check samples were collected. Effects of rock weathering of all sites were kept to a minimum by collecting large samples and breaking them down to the freshest material for thin sections and chemical analyses.

A third sampling phase related specifically to the north alluvial area (fig. 4) where sand-gravel samples were collected from dry washes draining the area. The 22 sample points ranged from 600 to 800 feet apart. The purpose of this phase was to define trace element distribution patterns in the alluvial area and determine if hidden mineralization might be present.

Previous Work

Early mining history of this area is vague. Lindgren's (1909) comments and Anderson's (1957) brief account of the Tres Hermanas district are perhaps the most notable contributions. Darton (1916 and 1917) supplied additional information on the mineral deposits. Balk (1962) studied the geology of the Tres Hermanas Mountains in detail and his geologic map and notes (1952) were utilized by Griswold (1961) in a report on the mineral deposits of Luna County, New Mexico.

Clarke's findings (1924) that 99 percent of the earth's crust is made up of 10 elements with atomic numbers less than 27, inspired many geologists to determine the behavior of the other elements present in trace amounts. V.M. Goldschmidt with his associates (1950) pioneered in this field using spectrochemical techniques. In a period of 7 work years he determined the distribution patterns of about 50 trace elements in the rocks of the earth's crust, and enunciated several laws. These contributions, and those of other workers, gave geochemistry its present status.

Nockolds and Mitchell (1948) discussed the factors controlling the distribution of major and minor elements in a series of igneous rocks.

Wager and Mitchell (1951) determined the geochemical trends of trace elements in minerals in a series of igneous rocks which changed in composition during fractionation and concluded that rock composition did not represent the composition of its original magma. De Vore (1955) suggested the possibility that metamorphic transformations liberate ore-forming metals.

Jedwab (1956) showed that the trace element content of a mineralized mica granite differed extensively from that of a non-mineralized one.

Parry and Nackowski (1960) analyzed the biotites from a monzonite stock in the Basin and Range Province and attributed the high content of copper in biotite, not only to lattice substitution but also to inclusions of chalcopyrite.

Theobald and Havens (1960) studied a hydrothermally altered quartz monzonite sill in Summit County, Colorado, and found that alteration of biotite resulted in loss of iron and other base elements.

Putman and Burnham's (1963) extensive study of biotites in igneous rocks from northwest Arizona suggested that minor element contents in the biotites from the same pluton varied only slightly but significantly from one pluton to another. They suggested that the copper and zinc is contained in the ferromagnesian phases, oxides and sulphides,

Figure 2 – Three Sisters Peaks (Tres Hermanas), Luna County, New Mexico.

Figure 3 – South Peak with a xenolith surrounded by granite-quartz monzonite.

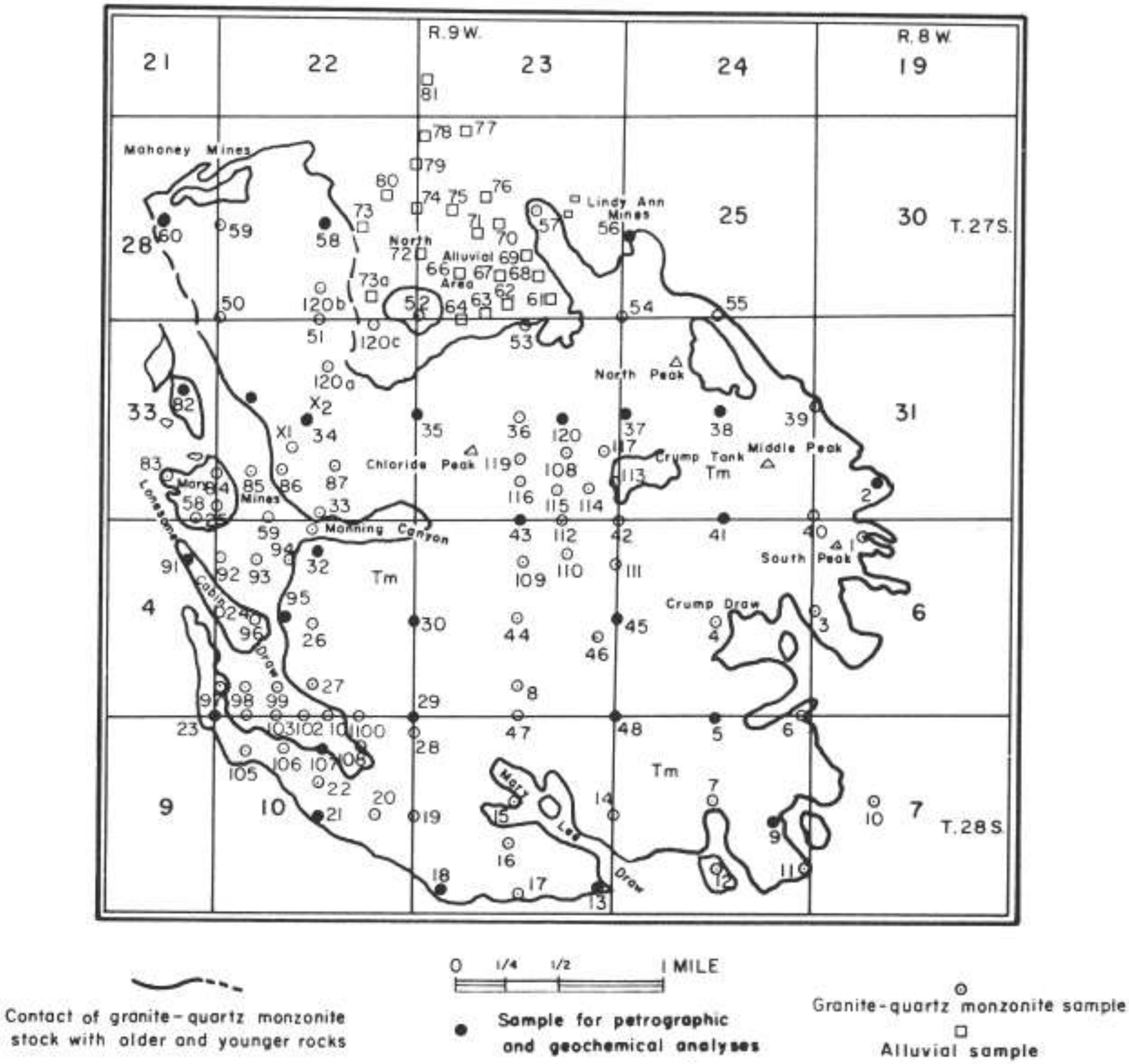

FIGURE 4—*Sample location map.*

and that in areas of known copper mineralization, the associated plutonic bodies contain high copper content.

Griffitts and Nakagawa (1960) in a study of unaltered monzonite intrusives in the western United States said that most anomalous metals are affixed to augite, hornblende, biotite, and sphene. They concluded that the high copper and zinc content of igneous rocks near such ore deposits was due to leakage from deposits during mineralization rather than to an originally high metal content of the parent magma.

Mackin and Ingerson (1960), in the Iron Springs district of southwestern Utah, showed that the iron, originally incorporated in biotite and hornblende, was released during deuteric alteration in the deeper parts of the laccoliths. Trace and major metals were locked in the peripheral shell. They advanced a significant deuteric release hypothesis for ore deposit origin.

Belt (1960), using a systematic sampling technique, analyzed samples from the Hanover Fierro intrusive stock for copper and zinc. He states that in an igneous country rock, in an area of few veins bearing metals, the metal ion distribution of a given metal is apt to be related to primary igneous texture, composition and other features but is not related to alteration. Conversely, in a similar rock cut by numerous veins bearing metals, the metal ion distribution is statistically far more clearly related to alteration than to primary igneous features.

Shrivastava and Proctor (1962) carried out spectrographic analyses of selected rock samples and their constituent minerals from the Searchlight stock, Nevada. They suggest that the trace element content in the ferromagnesian minerals might bear a relationship to spatially distributed mineral deposits around the stock.

Proctor and associates at Searchlight (1972) further investigated the spatial relationships of the whole-rock trace element content. They conclude that well-defined distribution patterns of the trace contents of gold, silver, copper, lead and zinc appear to be related to rock alteration and spatially associated mineral deposits.

Brownlow and Mantei (1966) in a study of the trace gold content of the Marysville stock, Montana, conclude that a definite relationship exists between the stock and the gold deposits.

Putman and Alfors (1969) studied the Rocky Hill nonproductive granodiorite stock, Tulare County, California. They state that a variation in trace element content occurs in granitic plutons, those of discrete mineral phases being characteristic and identifiable attributes quite useful for correlating genetically related units. The mineral phase trace element data creates problems where modally variable (magnetite) coexisting phases are involved. They also found that bulk-rock trace element data is better than mineral-phase trace element data and note that sampling should be governed by the nature of local variations.

Al-Hashimi and Brownlow (1970), on the basis of 61 biotite samples from the Boulder batholith (Late Cretaceous), observed that the higher copper values in Butte quartz monzonite biotites are higher than in the other magmatic units of the Boulder batholith, and are due to minute inclusions of sulphide minerals in the biotite, rather than to extensive isomorphic substitution of copper in the crystal structure, and is related to known mineralization. They feel that the copper content of minerals cannot be an effective tool for exploration because of copper's variable behavior in silicate melts.

Mantei, Bolter and Al-Shaieb (1970) conclude from a study of trace elements in 125 whole-rock samples from the productive Marysville, Montana, granodiorite stock and surrounding metamorphic rocks that systematic analysis of igneous bodies could be useful in exploring for hydrothermal ore deposits.

Other investigations specifically related to quartz monzonite intrusive bodies are discussed in a later section. These include Vinogradov (1962), Ahrens (1965), Taylor (1965), Putman and Burnham (1963), and Lovering, et al, (1970).

GEOLOGIC SETTING

Lit hology

For the purpose of this investigation, the lithologic units in the study area consist of sedimentary, intrusive and extrusive rocks. A generalized geologic map, modified from Balk (1962), shows the distribution of these units in the main part of the Tres Hermanas mining district (fig. 1).

Sedimentary Rocks

The sedimentary rock strata consist of Silurian, Mississippian-Permian, Lower Cretaceous, and Quaternary units with the probable existence of some Tertiary alluvium beneath the more recent deposits (Kottlowski and Foster, 1963). The Paleozoic sequence crops out north of the Tres Hermanas stock with a total thickness approximating 2000 feet.

Rocks of probable Early Cretaceous age on the west side of the area approximate 1530 feet in observed thickness. The lower and upper contacts are faults hence the actual thickness is probably much greater. The upper contact is faulted against massively bedded Gila Conglomerate (Cenozoic).

Quaternary sedimentary rocks consist of alluvial fan materials. These cover the bolson plains surrounding the mountains and also extend into the principal arroyos where they unconformably overlie all older rocks.

Intrusive Rocks

Intrusive rocks consist of: a) andesite, b) granite-quartz monzonite, c) monzonite, latite and rhyolite dikes and d) basalt dikes.

Hornblende-rich intrusive andesite occurs as two sub-rectangular bodies (Griswold, 1961, p. 25) on the northeastern margin of the Tres Hermanas Mountains and is thought to be older than the main body of quartz monzonite.

Granite-quartz monzonite forms a roughly circular stock about 10 square miles in area in the central part of the Tres Hermanas Mountains. This monzonite invades an andesite flow sequence along the southern edge of the stock and Paleozoic sediments along the northern boundary.

Apophyses extend outward into the older rocks. Dikes with compositions identical to the granite-quartz monzonite stock, but varying in texture from aphanitic to porphyritic, occur in, and extend outward from, the stock along fractures.

Extrusive Rocks

Three main extrusive rock units of probable Tertiary age are recognized: 1) older latite, 2) intermediate andesite, and 3) younger latite.

The older latite consists of a sequence of breccias, tuffs and subordinate flows exposed along the western part of the district (fig. 1), covering approximately 3 square miles. A porphyritic to aphanitic light gray latite is exposed near the Cincinnati mine.

Andesites almost surround the entire southern edge of the Tres Hermanas Mountains. The rock is layered to massive and consists of flows, breccias, agglomerates and tuffs. Thickness of the sequence is unknown.

The younger latite consists of breccias, tuffs and flows, of unknown thickness that crop out at the southern end of the Tres Hermanas Mountains (fig. 1) in a series of lobes extending over the older andesite.

Structure

The sub-circular stock of granite-quartz monzonite invaded Paleozoic sediments, possibly Cretaceous sediments, and several Tertiary volcanic rock sequences in an area of about 10 square miles. A much smaller, stock-like andesite probably is cut by the stock. Xenolithic masses of marbleized and silicified limestones up to half a mile in length occur at or near the granite-quartz monzonite intrusive contact (fig. 3). Dikes of monzonite, rhyolite and latite of predominantly northeasterly trend (one of north-north westerly, and several of west-northwesterly) and up to two miles in length, transect the intrusive and andesitic volcanic rocks.

Intruded Paleozoic sediments on the north end of the granite-quartz monzonite stock are gently to moderately inclined. Near the Mahoney mines they dip 17 degrees northward. To the east, near the Lindy Ann area, the beds strike northward and dip up to 45 degrees eastward. Cretaceous sediments, about 2 miles west of the main stock, trend generally northwestward but show considerable variation in dip with local inclination of up to 80 degrees. These attitudes contrast sharply with those of the Paleozoic rocks and suggest an unknown structural element. Tertiary volcanic rock structure apparently has not been delineated, nor have the attitudes of the Tertiary-Quaternary gravels. A late, nearly horizontal, eroded basalt forms an incomplete arc around the stock and intruded sedimentary and volcanic rocks.

Large-scale folds in the area are lacking, although local small folds are present (Griswold, 1961). At least 2, possibly as many as 4, sets of faults cut the Paleozoic, Mesozoic and Cenozoic rocks. Faults of northwest trend outline a horst-like block of Cretaceous sediments. A northwest-bearing fault also bounds the Mahoney mine area on the west. Faults trend generally northward in the exposed Paleozoic rocks in the Lindy Ann mine area.

A second fault set trends east-northeast through Cretaceous sediments and Paleozoic rocks in the Lindy Ann area. A third fault set bears northeast on the west side of the intrusive stock. Finally, Griswold (1961, p. 51) describes a small thrust fault of northwestward trend in the Lindy Ann area.

Joints are prominent in the granite-quartz monzonite with northeast and northwest sets dominant. These are steeply inclined. A nearly horizontal set is less prominent, as are less abundantly developed, steeply inclined north-south and east-west sets (see fig. 5 and 6).

Figure 5 — Joint pattern in South Peak, Tres Hermanas stock.

Figure 6 — Tres Hermanas stock showing joint sets on east side of intrusive body.

Dikes generally parallel the east-northeast fault set with some trending northeasterly. Other dikes in the south. east part of the area follow a west-northwesterly trend.

Mineral Deposits

Two types of mineral deposits occur in the Tres Hermanas area: 1) manto-like limestone replacement bodies, and 2) vein deposits in vertical fractures and/or faults (Griswold, 1961, p. 51).

The manto-like bodies are the most productive ore bodies. They occur in the "lower marble unit" of the Escabrosa Limestone (Mississippian) with the largest ore bodies in the Mahoney mines area. They may have associated silication. Favorable limestone beds elsewhere in the section may contain other undiscovered replacement deposits adjacent to feeder faults.

Vein deposits with some replacement features are controlled by faults and fractures in the Paleozoic rocks. The principal mineralized faults trend mainly east, whereas north-trending veins have been less productive. Vein ore is mineralogically similar to the manto type, although the ore shoots are much more irregular. They consist of numerous closely spaced veinlets in a zone as much as 4 feet thick. Veins are best developed in the latite flows and breccias, moderately developed locally in granite-quartz monzonite, and weakly developed in Paleozoic limestones. As an example, the Cincinnati vein system is a series of short disconnected veins with an aggregate length of 10,000 feet, a strike of N. 75° E. and inclination ranging from 75° to 80° S. and N. A vertical latite porphyry dike trending N. 25° W. terminates abruptly against the north side of the vein.

Mineralogy of Ore Deposits

Chief metallic minerals of the Tres Hermanas mining district are those of zinc and lead with subordinate silver, copper and gold. Minerals of the Mahoney mining area are listed in table 2 (from Griswold, 1961).

TABLE 2—*Ore mineral assemblage in Mahoney mining area*

Primary Zone		Secondary Zone	
Ore	Gangue	Ore	Gangue
Sphalerite	Calcite	Willemite	Calcite
Galena	Pyrite	Calamine	Limonite
Chalcopyrite	Wollastonite	Smithsonite	Manganese Oxides
Willemite (?)	Garnet	Hydrozincite	Quartz
Scheelite (reported to be present)	Epidote	Cerussite	
	Magnetite	Anglesite	
	Quartz	Azurite	
		Malachite	
		Cerargyrite (?)	

All of the sulphide minerals are thoroughly oxidized and only occasional remnants of sulphides remain at the surface. Hypogene zoning is suggested by the Cincinnati vein system with pyrite, lead-zinc sulphides, considerable quartz and calcite, and gold and silver, whereas farther west, in the Lower Cretaceous sediments, the veins contain abundant iron and manganese oxides with only minor oxidized lead and zinc. Scheelite is reported in a tactite zone near South Peak.

Age of Mineralization

According to Griswold (1961, p. 38) mineralization took place after the intrusion of the granite-quartz monzonite but prior to the invasion of the basic dikes. He concludes that the latite volcanic sequence and ore deposition were nearly contemporaneous and postulates that most of the ore mineralization in the district originated from deep seated differentiated products of the stock released during several different periods, from the time of stock emplacement to a period prior to emplacement of the basic dikes.

PETROGRAPHY OF GRANITE-QUARTZ MONZONITE STOCK

The stock is irregularly sub-circular in outline, with small apophyses extending outward into the surrounding sediments. The granite-quartz monzonite is pinkish gray to brownish gray where fresh, and yellow to brownish black in altered zones. The rock varies in grain size and texture. Porphyritic textures are present. Groundmass of the porphyry is mainly equigranular and shows a granitic texture. Near marginal contacts, the groundmass is granulitic. In areas of alteration, the feldspars, particularly plagioclase, tend to be lath-shaped and simulate a diabasic texture devoid of pyroxene. In these same general areas exsolution textures are profuse. The grain size of the essential minerals in the groundmass ranges from 0.2 mm to 0.4 mm in the marginal area of the stock. Locally it is as much as 0.4 mm to 0.8 mm in the interior, and in some places approaches the coarser range near the margins.

The phenocrysts do not show any particular size pattern. They range from 1.5 mm to 5 mm in diameter and occur throughout the stock. All 120 thin sections examined show porphyritic texture (table 3).

Granophyric, perthitic and antiperthitic, and myrmekitic textures also are present (table 3). A spatial relationship of these textures to altered areas of the stock is apparent. Their local abundance seems related to the concentration of the trace zinc, lead and copper in the stock.

Mineralogy

Major essential minerals of the Tres Hermanas granite-quartz monzonite porphyry consist of potash feldspars (orthoclase and minor microcline), plagioclase (mostly oligoclase-andesine) and quartz. Minor essential minerals are biotite, occasional muscovite, hornblende (sometimes tremolite), hypersthene, diopside, and aegirine-augite. The accessory minerals consist of apatite, zircon, magnetite, occasional dumortierite and rare sphene. Alteration products include kaolinite, sericite, chlorite, limonite and very subordinate epidote. Quartz of a secondary character also occurs.

The volumetric mineralogical composition of the rock (including alteration products) from a study of 34 grid samples is given in table 4. A triangular diagram of quartz-plagioclase-K feldspar) for the 34 samples is shown in fig. 7. Ten samples fall within the quartz monzonite (adamellite) range. A few are very close to it, and the remainder fall within the granite range. For this reason the stock is described as granite-quartz monzonite, although differing from the rock classification used by Griswold (1961) and Lindgren (1909).

Essential Minerals

Orthoclase feldspar: Orthoclase is the dominant feldspar and forms between 41 percent and 68 percent of the rock. It makes up a major portion of both the groundmass and the phenocrysts. The orthoclase of the groundmass ranges in diameter from less than 0.1 mm to as much as 0.8 mm, while phenocrysts range from 1.5 mm to 5.5 mm. Where altered, the orthoclase is turbid brownish gray, probably due to minute kaolinite dispersed throughout the mineral; and shows perthitic and granophyric textures. In some areas of intense alteration, orthoclase feldspars appear broken but still show optical continuity. Putman and Burnham (1963) describe such a texture and state that it may be due to shattering and/or cataclastic deformation. Zoning and Carlsbad twins are common in orthoclase. Orthoclase

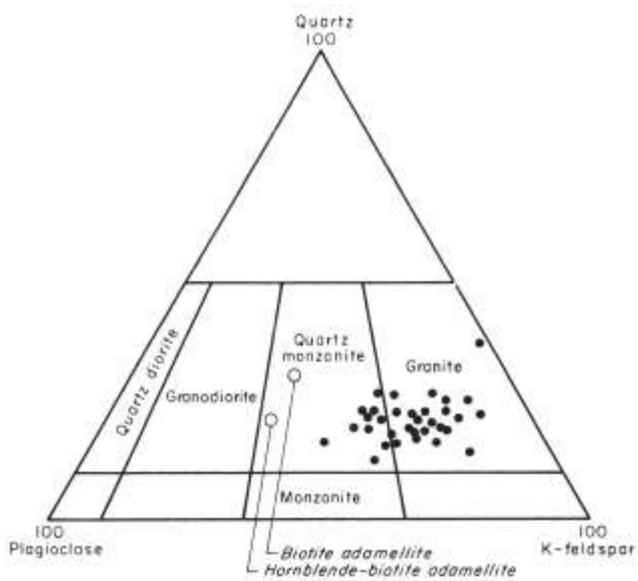

FIGURE 7—*Modal distribution of quartz, potash-feldspar, and plagioclase in 34 samples from the Tres Hermanas granite-quartz monzonite stock.*

is generally altered to kaolinite. In many cases, primary optical properties of the feldspar are clearly preserved and only in the most intense alteration do they commonly disappear. Occasionally microcline forms the core of an orthoclase phenocryst. This suggests a transformation to orthoclase.

Plagioclase feldspar: The composition of the plagioclase ranges from oligoclase to andesine. Generally, it constitutes from 4 to 33 percent of the rock. Grain size of the groundmass plagioclase ranges from 0.3 mm to 1.0

TABLE 3–*Grain size and textures in granite-quartz monzonite* (I=intense, M=moderate, W=weak, VI=very intense, MW=moderately weak, VW=very weak, P=perthitic, V=vermiform texture, Myr=myrmekitic, S=sieved, E=embayment of feldspars)

Sample No.	Feldspar grain size (average) Phenocryst mm longer axis	Groundmass mm	Textures Granophyric Texture	Other Features
1	2.3	.4		
2	2.45	.4	M	
3	2.1	.3		
4	1.9	.45	I	V
5	2.6	.5		
6	1.6	.45	I	Myr
7	1.9	.5		
8	2.3	.5		
9	2.2	.4		
11	2.0	.4		
12	2.2	.6	I	
13	2.3	.4	M	P
14	2.2	.4		
15	2.3	.3		
17	2.4	.5		
18	2.6	.5		V
19	2.0	.4		
20	2.0	.4		
21	2.0	.5	W	P
22	—	.1		
23	2.5	.7	M	
24	2.0	.3		
25	2.1	.5		
26	2.0	.4		
27	3.1	.6	M	
29	2	.7		
30	1.6	.4	S	
31	3.7	.8		
32	1.75	.4		
33	1.8	.4	VI	
34	1.3	.6	M	
35	2.5	.4	M	
37	2.3	.4	M	
38	2.4	.4	M	
39	3.5	.3		
40	2.5	.6	I	
41	2.6	.5	M	E
42	2.2	.7		
43	1.3	.4		
44	1.4	.4	M	
45	1.4	.4		
46	1.7	.4		
47	3.5	.45	I	
48	2	.5		
49	.5	1.8	M	
50	.4	.6	M	
51	1.7	.3		
52	2	.35		
53	1.8	.6	M	S,E
54	3.1	.5	M	E,Myr
55	1.46	.4		
56	2.3	.2		
57	1.8	.3		
58	1.6	.5	M	
59	2.2	.6		
60	1.5	.5	I	E
82	1.8	.3		
83	1.9	.3		
84	2.3	.6		P
85	2.1	.6		
86	2.1	.6		
87	2.7	.3		
88	1.8	.45		
90	1.8	.5	M	
91 (2)	2.5	.7		
91 (3)	2.2	1.0		
91 (4)	1.8	.45	M	E
91 (7)	1.9	.5		
94	1.9	.4	M	Myr, E, P
95	2	.5		
96		.5		
97		.4		
98	1.9	.4	M	P
99	2.1	.3		
100	1.5	.32	W	Myr, P
101	2.3	.35	MW	
104	2	.6	VW	
105	2.0	.6		
106	.5	.1	W	
107	2	.4		
108	2	.4		
109	2.3	.5	M	Myr
110	1.5	.3	W	
111	2.4	.4	M	E
112	2.0	.3		
113	2.25	.6	W	
114	2.1	.5	VW	Myr, E
115 (T)	3.8	.3	M	V, E
116	2	.4	M	V, E
117	1.7	.6	M	
118	1.7	.6	M	
119	1.3	.3	M	
120	1.2	.3		
x1	1.8	.3		
x2	1.8	.4		

mm, while that of the phenocrysts ranges from 1.5 mm to 5.25 mm. Grains are subhedral to euhedral. Lath-shaped grains also were noted which are locally bent and show wavy extinction. Paired twins are common and zoning tends to be more sodic toward the periphery. Perthitic (plumose) and myrmekitic textures are prominent in some areas of intense alteration. Plagioclase is generally moderately altered to sericite, and to a lesser extent to clay minerals.

Quartz: Quartz grains range in diameter from 0.6 mm to 2.0 mm and form about 12 percent to 36 percent of the rock. Grains generally are anhedral, spongy, corroded or sieved. In the Tres Hermanas stock, quartz forms an essential part of the granophyric texture mentioned under orthoclase. It also is associated with myrmekite.

Biotite: Biotite occurs as dark-colored cleavage specks or as platy aggregates forming from less than 0.1 to 3.4 percent of the rock volume. Grains range from 0.3 mm to 1.0 mm in diameter and are not uncommonly euhedral, but more commonly subhedral and fibrous to strandy. Biotite is commonly associated with magnetite and hornblende suggesting a possible reaction relationship. Local grains enclose plagioclase feldspar, and in two instances, muscovite is included in the core. Chlorite and limonite are common alteration products.

TABLE 4–*Volumetric mineralogic-composition of Tres Hermanas granite-quartz monzonite, including alteration products*

Sample No.	Quartz %	Potash feldspar (orthoclase) %	Plagioclase %	Ferromagnesians % Biotite	Hornblende	Magnetite	Total	Argillic*	Alteration products of original rock % Sericitic*	Chloritic	Epidote	Limonite
2	13.00	67.00	16.00	.07	2.01	2.01	4.09	53.82	.18	.02	–	–
4	15.50	41.60	42.00	.02	.06	1.24	1.32	68.60	1.08	.03	.07	–
5	19.00	55.60	22.80	.06	.04	1.90	2.00	60.50	.67	.02	.02	–
9	18.50	57.00	21.00	.07	.82	2.16	3.05	37.10	.15	.02	.03	.01
13	20.80	62.50	9.36	1.68	1.07	4.58	7.33	57.36	1.64	.15	–	.31
18	23.40	58.20	13.43	.25	1.64	1.85	3.74	61.50	.91	–	–	.93
21	19.70	60.20	16.20	1.38	.46	2.13	3.97	60.20	.10	–	–	–
23	24.10	59.10	15.31	.17	.17	1.01	1.35	54.83	6.87	.52	–	–
29	17.80	60.25	17.60	1.27	.48	2.70	4.37	43.72	2.48	–	–	.32
30	20.80	49.00	25.69	.86	.68	1.88	3.32	53.75	1.25	1.03	.17	–
32	21.00	48.20	23.00	2.38	.55	2.56	5.49	48.70	6.30	2.18	.18	.55
35	12.53	50.50	32.20	1.51	.27	1.23	3.01	58.93	2.37	1.78	.14	–
37	18.70	53.25	23.50	.95	2.59	.95	4.49	52.04	1.96	–	.16	–
38	18.20	52.20	22.00	1.54	.37	4.45	6.36	40.77	2.73	.77	–	–
41	20.20	55.50	22.20	.55	–	1.25	1.80	40.92	1.83	.42	–	–
43	25.30	44.00	25.80	.58	–	.16	.74	29.70	23.80	–	–	4.48
45	21.00	46.00	28.00	1.20	1.58	2.32	5.10	52.00	–	.79	–	.20
47	15.90	53.50	25.70	1.56	–	2.59		50.00	5.52	.52	.17	–
48	18.60	54.20	19.20	1.89	.57	3.59	5.95	55.70	8.30	1.52	–	–
49	21.50	44.50	31.70	2.17	–	1.55	3.72	28.00	11.00	–	–	–
52	20.10	56.70	15.95	1.39	.46	5.08	6.93	40.32	6.93	–	–	.15
53	36.60	58.60	3.94	.62	–	.31	.93	56.44	1.56	–	–	–
56	24.50	62.00	11.40	.38	.19	.75	1.02	48.80	3.20	–	–	.38
58	25.20	55.00	16.30	2.16	–	.46	2.62	36.55	7.70	.93	–	.55
59	20.40	46.25	28.70	1.17	.20	.98	2.35	35.00	26.00	2.00	.20	
60	18.00	47.50	25.10	.77	–	4.00	4.77	32.70	36.80	4.15	–	1.54
82	21.00	48.00	30.00	–	–	.20	.20	44.00	–	–	–	–
91	18.58	59.41	18.58	.46	.62	2.31	3.39	43.89	3.36	–	–	.15
95	18.40	41.80	32.60	3.93	.37	.75	5.05	42.10	12.60	1.50	–	.90
107	25.50	49.00	23.50	–	–	1.94	1.94	27.45	25.80	–	–	.18
113	21.20	61.90	15.60	.20	–	1.20	1.40	24.52	3.98	.6	–	–
115	20.90	52.00	22.20	1.21	.35	2.60	4.26	41.64	10.01	1.21	–	–
120	21.00	53.00	20.06	1.34	1.69	1.23	4.46	47.25	5.25	1.23	–	–
x2	15.80	51.60	27.70	–	–	2.61	2.61	41.40	9.60	2.00	.15	.15

* Estimated–independent of other minerals

Hornblende: Hornblende occurs commonly but is subordinate to biotite, making up only 0.1 to 2.5 percent of the rock volume. Grain size is from 0.15 mm to 2.25 mm and forms are subhedral to euhedral and strandy. Hornblende is markedly pleochroic and occurs as paired twins. It generally is secondary after pyroxene, and in the southern border of the stock is of the uralite variety. Acicular tremolite is associated with the hornblende which also shares reaction relationships with biotite and magnetite. These relationships suggest that the hornblende replaces pyroxene and/or magnetite, and was partially replaced by biotite. Hornblende commonly alters to chlorite.

Pyroxene: Pyroxene is very subordinate in amount to other ferromagnesian minerals and is visible only under the microscope. Grains range from 0.6 mm to 1.3 mm. Based on pleochroism and extinction angles, probable diopside and aegirine-augite were recognized. Diopside is twinned, shows alteration to hornblende and chlorite and is also replaced by limonite.

Accessory Minerals

Magnetite: Magnetite is the dominant accessory mineral, occurring as dark metallic specks and constituting from 0.1 percent to 5 percent of the rock. Grain sizes range from less than 0.1 mm to 0.9 mm. It is indiscriminately distributed throughout the rock and even occurs in the cores of plagioclase. Relationships with hornblende are noted above. Limonite is an alteration product and fills hair-like partings in plagioclase.

Apatite: Apatite is generally euhedral and occurs as colorless to light blue prismatic crystals ranging in length from 0.7 mm to 0.14 mm. It is common as inclusions in magnetite.

Zircon: Zircon is usually short, euhedral, and occurs with magnetite. Grain size is about 0.06 mm.

Dumortierite: This mineral resembles zircon here but is distinguished from zircon by its length-fast character.

Sphene: This mineral occurs rarely, observed only in one section. The single crystal was euhedral.

Distribution of Primary Igneous Minerals

Iso-mineral plots of potash feldspar, plagioclase feldspar, quartz and the ferromagnesian minerals are illustrated in figs. 8, 9, 10, and 11, respectively.

The distribution of orthoclase feldspar, which composes 41 to 68 percent of the stock, is shown in fig. 8. Areas of relatively low orthoclase content occur near the Mahoney mines, Lonesome Cabin Draw and in the Crump Draw area. The areas of high orthoclase content are dominant in the marginal portions of the stock and upper Manning Canyon (Doraibabu & Proctor, 1972).

Plagioclase (oligoclase to andesine) composes 4 to 33 percent of the intrusive body and the iso-mineral plot is shown in fig. 9. The pattern is a rough reverse image of the orthoclase content.

Quartz constitutes 12 to 36 percent of the rock. Two areas of relatively low quartz content are shown in fig. 10. One is southwest of the north alluvial area; the other is a roughly crescent-shaped area in the east and south-eastern part of the stock. A small zone of high quartz content occurs south of the Lindy Ann mines area.

Distribution patterns of the restored primary volumes of the ferromagnesian minerals—biotite, amphiboles, pyroxenes and magnetite—are shown in fig. 11. Volume percentages range from 1.5 to 10 percent. Areas low in ferromagnesian minerals are apparent from the central part of the stock to Crump Draw, from the Lindy Ann mine area to the north-central part of the stock (2 to 4 percent), and another (2 percent) in the southwestern part of the stock. Spoke-like areas of higher content occur near Mary Lee Draw, Lower Manning Canyon, Mahoney mines area and a zone a mile north of Crump Draw.

Petrographic Characteristics and Mineral Deposits

Grain size of the granite-quartz monzonite groundmass averages 0.5 mm near the mineralized areas. The phenocrysts, among the smallest in the stock, range from 1.5 mm to 2.2 mm.

Small but recognizable variations occur in the primary mineral assemblages of the stock near the mineralized areas. Zones of highest K-feldspar content do not show any direct relationship to external mineral deposits. A zone of very low-grade zinc-lead mineralization occurs within the stock in the upper reaches of Manning Canyon and is spatially related to a low K-feldspar content zone. Plagioclase content, which is low to moderate (6 to 26 percent) near the external mineralized areas, decreases near the zone of low-grade zinc-lead mineralization. Quartz shows a sieve-like texture near the mineralized areas and the quartz content is fairly consistent at 20 percent near mineralized areas, except rising to 30 percent at the Lindy Ann mine.

Ferromagnesian minerals average around 4 percent near mineralized areas. Away from these, they range from 2 percent to as much as 7 percent. Intermediate to low content zones of ferromagnesian minerals near the mineralized zones may be partly the result of destruction by hydrothermal alteration. Accessory minerals, apatite and zircon, occur in decreased amounts near mineralized zones.

The petrological features described above coincide with definite patterns of trace base-metal anomalies described later.

Alteration of Granite-Quartz Monzonite

Alteration in the Tres Hermanas granite-quartz monzonite is evident to prominent in all but the southwestern part of the stock, where alteration ranges from weak to in

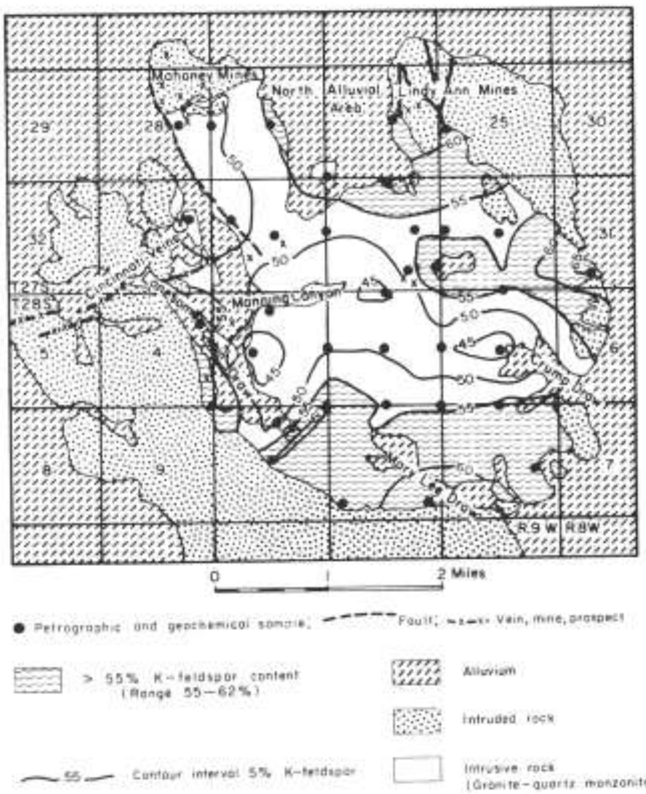

FIGURE 8—*Isomineral content of K-feldspar, Tres Hermanas stock.*

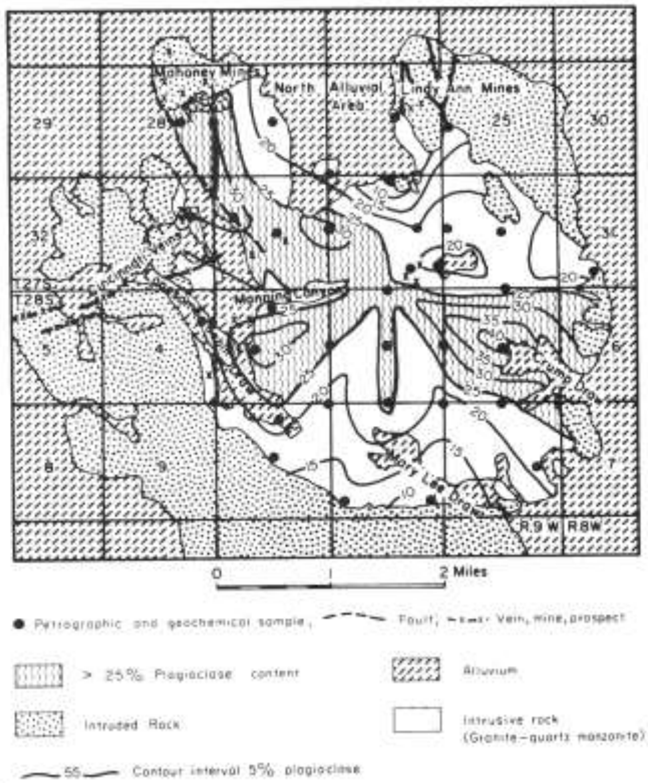

FIGURE 9—*Isomineral content of plagioclase, Tres Hermanas stock.*

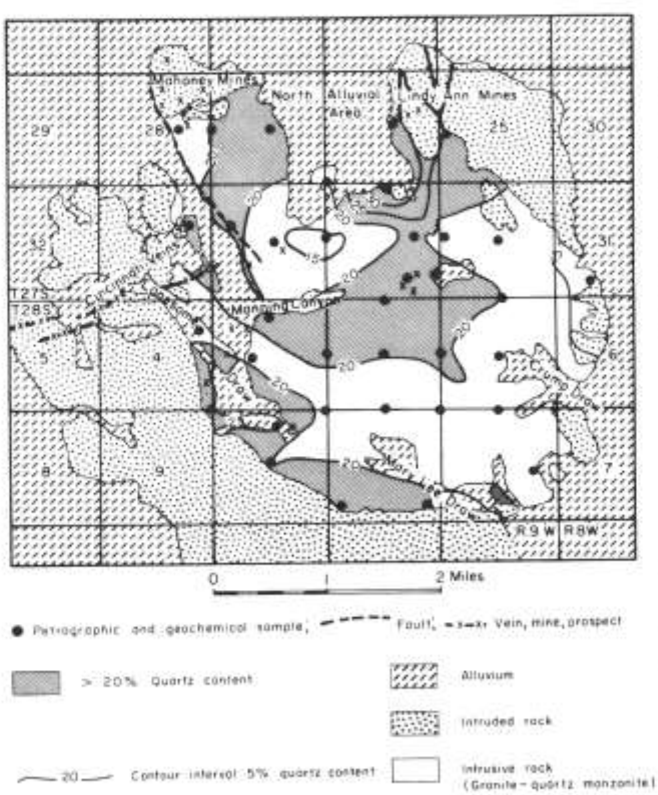

FIGURE 10—*Isomineral content of quartz, Tres Hermanas stock.*

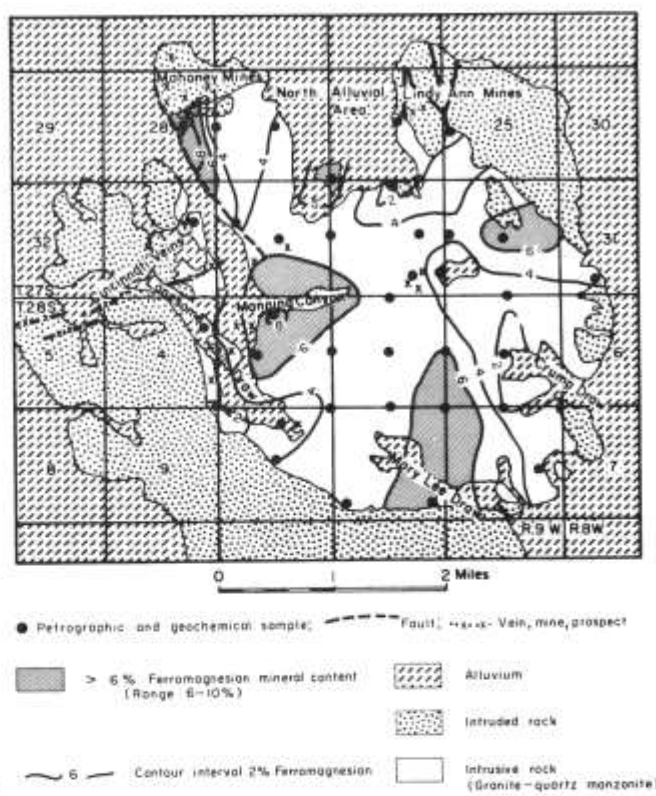

FIGURE 11—*Isomineral content of ferromagnesian minerals, Tres Hermanas stock.*

absent. Alteration is classified as weak (less than 5 percent of the rock affected), moderate (5 to 25 percent of rock affected), moderately intense (25 to 40 percent of rock affected) and intense (40 percent or more of rock affected), based on point count analyses of thin sections.

Kaolinitic, sericitic, chloritic, pyritic, limonitic and very minor epidotitic are the prevalent types of alteration present. The first three types were quantitatively estimated from a study of 34 rock samples collected on a grid from the stock. Results are presented in table 4. Alteration intensities are outlined for the stock in figs. 12, 13, 14.

The major part of the periphery of the stock has been intensely argillized with local areas showing moderate to intense alteration, decreasing toward the center. The ring-like alteration pattern on the western margin is broken by a T-like expanse of intense argillic alteration with the bar on the margin and the leg toward the center of the stock. In detail, the north-central, eastern south-central, and southwestern portions of the Tres Hermanas stock are intensely altered. The western and central parts of the stock show moderately intense alteration (fig. 12). The rest of the area shows lesser intensities of argillic alteration.

Sericitic alteration zones, characterized by the replacement of primary minerals, mainly feldspars, by sericite, are shown in fig. 13. A moderately intense alteration zone is surrounded by a moderate zone in the eastern two-thirds of the stock. A zone of moderately intense to intense alteration is rectangular in form and covers the western part of the stock. In the northwestern corner, near sample 60 and the Mahoney mines, the intensity of alteration is the highest, ranging up to 37 percent.

Chloritic alteration, characterized by the development of chlorite at the expense of primary minerals—mainly ferromagnesian types, is generally of weak intensity in the Tres Hermanas stock (fig. 14). Only the west-central and northwestern parts show readily recognizable areas of such alteration.

The most abundant chloritic alteration occurs in the northwestern part of the stock near sample 60 and the Mahoney mining area, ranging to about 4 percent of the total rock. Because chloritic alteration has affected only the ferromagnesian minerals, and their amount in the whole rock is low, the overall alteration intensity is weak.

According to Griswold (1961, p. 65) sericitization, kaolinization and pyritization are the prevalent types of alteration and, although small zones exhibit an intense degree of hydrothermal alteration, as near the Cincinnati vein system, the alteration of larger areas he classifies as mild to moderately altered.

Pyritic alteration zones are associated with limonitic staining in the northwestern and southwestern parts of the stock and this type of alteration is limited in distribution.

Epidote occurs as a minor alteration product in the stock and may have been derived from hornblende with which it occurs in close association. Limonite occurs as a reddish-brown weathering product in both the northwestern and southwestern parts of the stock. In a few thin sections, limonite occurs in the form of brown stains associated with magnetite and biotite, occasionally forming a dendritic pattern in magnetite. Limonite also fills minute fractures in feldspars.

Rock Alteration and Mineral Deposits

Patterns of argillic alteration (fig. 15) bear little or no consistent relationship with known mineralized areas. Possibly a large percentage of the argillic products are weathering phenomena. By itself argillic alteration does not serve as a guide to mineralization in the area.

Sericitic alteration (fig. 15) of varying intensities is fairly widespread within the stock. Some defmitive patterns occur. In Manning Canyon, the central sub-oval alteration zone is spatially related to a low-grade mineralized zone. A similar situation prevails in the low-grade mineralized areas in Lonesome Cabin Draw and near the Cincinnati vein area. The most intense sericitic alteration occurs in the stock adjacent to the Mahoney mines area. The Lindy Ann mining area, in carbonate rocks, shows little, if any, apparent relationship to sericitic alteration at the surface.

Zones of chloritic alteration are of limited intensity and related to primary ferromagnesian content of the rock. One zone is east of the Cincinnati vein system and the other near the Mahoney mines. None was recognized in the Lindy Ann mines area.

Griswold's (1961) zone of pyritic and argillic alteration of northerly trend (fig. 15) in the western part of the stock is distant from both the main mineralized area and the low-grade mineralized zones.

Mineral and Alteration Trends—
Relation to Mineral Deposits

Trends of the high primary mineral contents, the higher intensity alteration types, and the mineralized zones of the stock are shown in fig. 16. Spatial relationship of mineralization to these features is suggested. High sericite, high chlorite, and high ferromagnesian contents are almost coincident in the Mahoney mines area. Just north of the western part of Manning Canyon, high chlorite and highsericite trends coincide and are spatially related to a low-grade mineralized zone. In upper Manning Canyon, the high sericitic alteration trend is associated with low-grade mineralization. Trends of high quartz and plagioclase are adjacent. This area is also the focus for high contents of quartz, plagioclase, and adjacent high K-feldspar contents. At the junction of Manning Canyon and Lonesome Cabin Draw a high sericite trend intersects a low-grade mineralized zone.

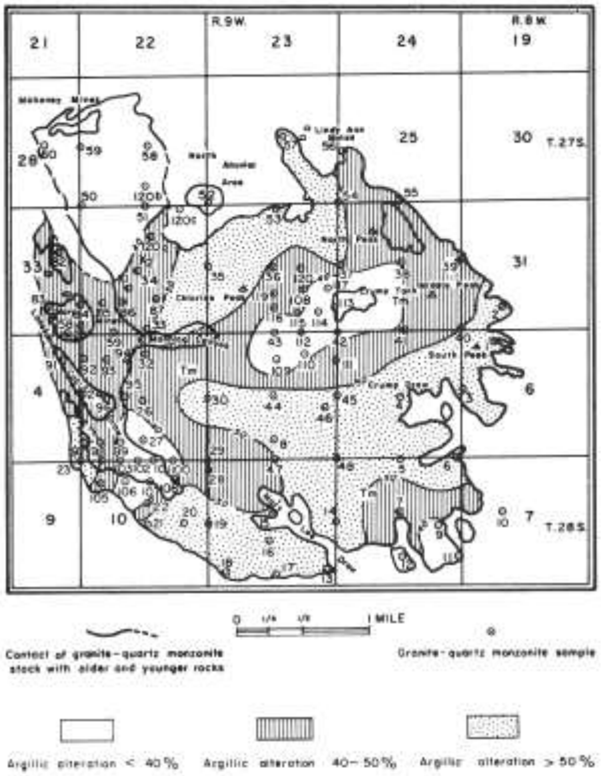

FIGURE 12—*Sketch map of areas of argillic alteration within the Tres Hermanas stock.*

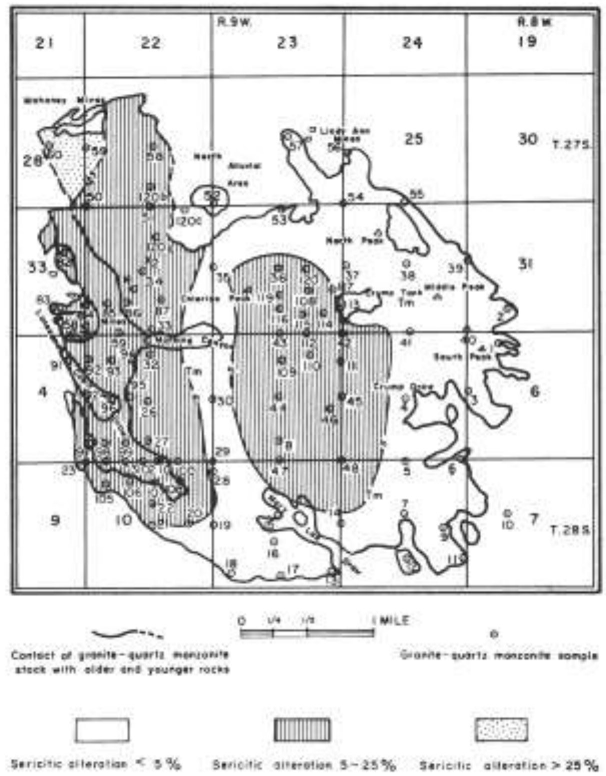

FIGURE 13—*Sketch map of areas of sericitic alteration within the Tres Hermanas stock.*

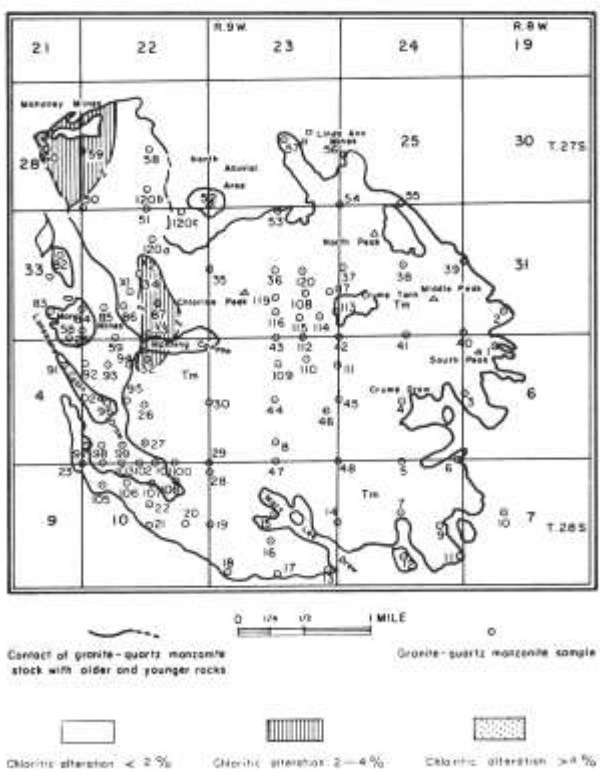

FIGURE 14—*Sketch map of areas of chloritic alteration within the Tres Hermanas stock.*

Alteration features are only weakly developed in the Lindy Ann mines area. The source of the mineralization is probably to the west. A high sericitic alteration trend swings eastward near the south end of the north alluvial area about a mile from the Lindy Ann mines.

Some primary mineral highs radiate outward from the center of the stock to the margins in a spoke-like arrangement, but mineralization is not known for these portions of the stock.

Figs. 15 and 16 suggest that mineralization and alteration are closely related. Sericitic and chloritic alteration are the most favorable guides to zones of mineralization. Absence or low intensity of sericitic and/or chloritic alteration may outline areas of least favorability for mineralization in and around the stock.

Collection of samples on a finer grid and more detailed petrographic study might define the alteration areas more precisely. Used in conjunction with other petrographic characteristics and base metal trace element patterns within the stock, more definitive spatial relationships could be established.

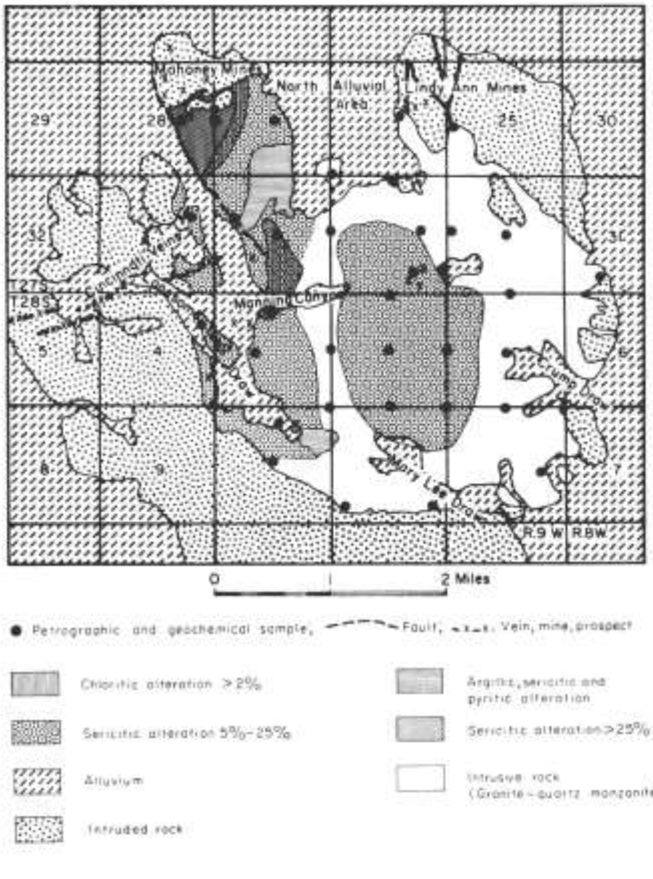

FIGURE 15—*Sericitic, chloritic, argillic, and pyritic alteration intensity map, within the Tres Hermanas stock.*

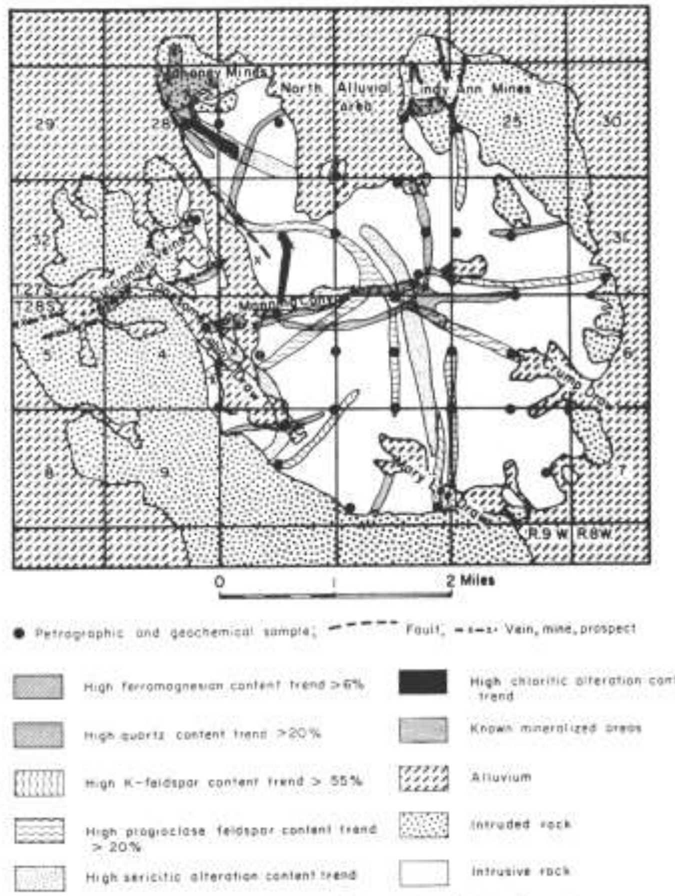

FIGURE 16—*Relationship of trends of high primary mineral content and alteration to known mineralized areas within the Tres Hermanas stock.*

TRACE BASE METAL ANALYSES AND INTERPRETATIONS

Trace contents of zinc, lead and copper were determined on grid samples from the intrusive body to determine possible spatial and genetic relationships between these contents and known mineral deposits surrounding the stock. Relationships between trace element contents, primary petrographic features, and alteration phenomena within the stock were also determined. Supplementary alluvial samples from the north alluvial area were collected and analyzed.

Atomic absorption bulk-rock analyses of 150 samples and the 22 alluvial samples for each base element were plotted on a base map of the area and the following interpretations made:

1) Spatial trends of the trace contents of each of the heavy metals (zinc, copper and lead) in the stock and in the alluvial covered area to the north.
2) Distributional relationships among zinc, lead and copper concentrations within the stock.
3) Spatial relationships of the base metal concentrations to known mineralized areas in and around the stock.
4) Patterns of trace element concentrations and their relationship to alteration zones within the intrusive body.

Results of the atomic absorption analyses for zinc, copper and lead are presented in tables 5 and 6. The arithmetic mean and the standard deviation for the samples are also indicated.

Distribution of Zinc, Lead and Copper

Background values for zinc, lead and copper were calculated for the stock from fresh rock samples from areas showing least alteration in the eastern and southeastern parts of the body (table 7).

Distribution of zinc, lead and copper concentrations in 99 samples from the Tres Hermanas stock are shown in figs. 17, 18, and 19. Outlines of the anomalous high areas are indicated. The bases for outlining each metal anomaly are described in the text.

Clarke (1924) presents analyses of the major rock types occurring in the earth's crust. These analyses were limited mostly to the oxides of the major metals and nonmetals. Goldschmidt (1950) first showed the significance of trace elements in crustal rocks. He suggested the crustal abundance of zinc, lead and copper is 80 ppm, 16 ppm, and 70 ppm, respectively. Later workers such as Vinogradov (1962) and Ahrens (1965), in specific geochemical studies, determined the trace contents of many other elements in the crust and in various rock types. Taylor (1965), and Putman and Alfors (1969) related them to petrological characters of rocks. Ore genesis, mineral exploration guides and trace element content were described by Shrivastava and Proctor (1962), Putman and Burnham (1963), Al-Hashimi and Brownlow (1970), Mantei, Bolter and Al-Shaieb (1970), T. G. Lovering (1970) and others.

Average concentrations of zinc, lead and copper for the crust and intermediate igneous rocks from Goldschmidt, Vinogradov and Ahrens, show 71 ppm for zinc, 14 ppm for lead and 53 ppm for copper.

Zinc Concentrations in Stock

Three major divisions of zinc content are indicated in fig. 17: 1) Concentrations of zinc less than 80 ppm, 2) Zinc concentrations from 80-100 ppm, and 3) Zinc concentrations greater than 100 ppm. The anomalies shown are based on specific samples and related samples which surround them as noted in table 8.

Anomaly Z-1: At least 6 samples have zinc concentrations above background, three of which are above 80 ppm. Zinc concentration increases toward sample 58 in an easterly to northeasterly direction. The range of zinc content is from 52 to 750 ppm. Alluvium bounds this portion of the stock on the east and west.

Anomaly Z-2: Twenty-eight samples carrying zinc contents above background, with 19 containing more than 80 ppm zinc, constitute this anomaly. Values tend to increase toward the center of the anomaly. The central part of the anomaly is best developed in the lower elevations of the upper part of Manning Canyon where 12 surface samples show more than 80 ppm zinc. A drill hole, located near sample 115, shows an increase in zinc content from the surface downward. Sample 116, at the mid-eastern part of the anomaly shows a value of 500 ppm zinc. Zinc in surrounding samples increases toward this sample.

Anomaly Z-3: Seven main samples constitute this anomalously high zinc area in the lower part of Manning Canyon and into Lonesome Cabin Draw. The highest zinc concentrations in the stock were recognized near sample 91-4 with 1625 ppm. The zinc anomaly is outlined by seven samples carrying over 80 ppm zinc content. The trend within the anomaly is delineated by 20 samples carrying zinc concentrations over the background value. The range of zinc concentrations within the anomaly is 74 to 1625 ppm.

Anomalies Z-4, 5, 6, and 7: These are together because they are delineated by zinc concentrations above 80 ppm but linked by related samples which have above background values of zinc, and because they indicate the trend in the zinc values. The range of zinc concentration in the

TABLE 5—*Atomic absorption analyses of rock samples, Tres Hermanas stock*

(metal content ppm)

Sample location	Zinc	Lead	Copper
1	60	32	5
2	60	35	4
3	60	46	5
4	65	37	9
5	60	42	5
6	55	32	7
7	62	35	6
8	77	46	5
9	37	27	4
10	57	42	5
11	65	42	7
12	75	32	9
13	60	35	9
14	65	42	5
15	45	30	5
16	65	32	3
17	97	30	4
18	52	32	14
19	90	30	11
20	90	32	7
21	80	35	4
22	80	35	13
23	75	38	5
24	66	41	6
25	85	45	3
26	37	27	4
27	80	46	5
29	55	41	5
30	87	50	13
31	60	50	5
32	127	55	17
33	60	35	6
34	152	50	8
35	87	32	7
37	57	38	6
38	65	38	5
39	32	27	7
40	117	67	5
41	65	38	5
42	92	45	4
43	90	35	4
44	75	35	7
45	70	32	6
46	37	25	4
47	97	42	8
48	55	49	3
49	87	36	9
50	177	69	19
51	52	25	3
52	62	37	5
53	117	66	9
54	90	70	10

Sample location	Zinc	Lead	Copper
55	40	36	3
56	37	34	3
57	85	52	7
58	750	290	17
59	77	52	13
60	72	47	7
82	30	32	4
83	32	34	3
84	50	30	6
85	47	27	7
86	72	37	10
87	30	41	5
88	500	41	6
90	47	35	4
91-2	72	45	5
91-3	122	42	5
91-4	1625	177	8
91-5	447	35	5
91-7	102	35	5
94	74	40	5
95	105	41	10
96	150	61	6
97	70	32	5
98	65	40	5
99	50	41	5
100	85	47	9
101	74	50	11
103	70	45	5
104	117	42	5
105	117	50	7
106	32	29	6
107	47	30	4
108	72	42	7
109	145	29	5
110	110	35	10
111	155	35	3
112	87	37	6
113	74	34	6
114	137	42	8
115 (top sample)	65	41	5
116	500	27	6
117	100	37	9
118	135	229	7
119	137	45	10
120	74	31	4
97	35	19	3
	80	26	4
Arithmetic Mean	112	45	7
Standard Deviation	184	36	3

group is from 50 ppm to 117 ppm. The zinc concentration in anomalies Z-4 and Z-5 shows a westward-increasing trend, and in anomalies Z-6 and Z-7, shows an eastward-increasing trend.

Anomaly Z-8: An anomalous zinc concentration greater than 80 ppm zinc occurs in a valley slope on the northwestern flank of South Peak. The range of zinc content in the anomaly is from 60 ppm to 117 ppm. Although random local variations in zinc concentrations do occur in the igneous body, alignments of anomalies is strongly indi-

TABLE 6—*Atomic absorption analyses of soil samples, Tres Hermanas Mountains*
(Alluvial Area—Secs. 26-27, T. 27 S., R. 9 W.)

Sample Location	Zinc	Lead	Copper
61	250	34	12
62	250	110	16
63	225	45	18
64	152	20	12
65	125	17	13
66	126	47	8
67	86	27	8
68	100	30	12
69	112	27	16
70	308	40	13
71	72	27	12
72	100	37	12
73	126	27	9
73A	124	27	16
74	137	34	14
75	50	31	13
76	113	35	15
77	99	42	19
78	187	40	20
79	62	32	12
80	133	27	8
81	75	35	12
Arithmetic Mean	137	36	13
Standard Deviation	67	18	3

TABLE 7—*Average background values for zinc, lead and copper, Tres Hermanas stock*

Sample Number	Zinc	Lead	Copper
1	60	32	6
2	60	35	5
6	55	32	8
7	62	35	7
9	37	27	5
15	45	30	6
55	40	36	3
56	37	33	4
Total	396	260	44
Average	49	33	6

TABLE 8—*Zinc anomalies, specific and related samples, Tres Hermanas stock*

Anomaly No.	Specific samples (Sample No. followed by zinc	Related samples content, ppm, in parentheses)
Z-1	49 (87), 50 (177), 58 (750)	51 (52), 59 (77), 60 (72)
Z-2	27 (80), 30 (87), 34 (152), 35 (87), 42 (92), 43 (90), 53 (117), 54 (90), 57 (85), 109 (145), 110 (110), 111 (155), 112 (87), 114 (137), 115 (65), 116 (500), 117 (100), 118 (135), 119 (137)	29 (55), 31 (60), 37 (57), 41 (65), 44 (75), 99 (50), 120 (74)
Z-3	25 (85), 26 (37), 32 (127), 33 (60), 91-2 (72), 91-3, (122), 91-4 (1625), 91-5 (447), 91-7 (102), 95 (105), 96 (150)	87 (30), 97 (70), 98 (65), 99 (50), 31 (60), 83 (32), 84 (50), 85 (47), 86 (72)
Z-4	104 (117), 105 (117)	23 (75), 101 (74), 103 (70), 106 (32)
Z-5	19 (90), 20 (90), 21 (80), 22 (80)	16 (65), 27 (80), 107 (47), 108 (72)
Z-6	17 (97)	13 (60), 15 (45), 18 (52)
Z-7	47 (97)	14 (65), 29 (55), 44 (75), 45 (70), 48 (55)
Z-8	40 (117)	1 (60), 2 (60), 3 (60), 4 (65), 5 (60), 38 (65), 39 (32), 41 (65)

cated (fig. 17). An east-west trend is discernible through sample locations 40, 41, 111, 109, 91-2 to 91-7 and 88. A possible north-south alignment is suggested through samples 104 and 105 of anomaly Z-4, the samples of 91 group and sample 88 in anomaly Z-3, plus samples 49 and 50 of anomaly Z-1. Another north trend occurs through samples 53, 36, 116, 48 and 44, possibly continuing through anomalies Z-8 and Z-6. The intervening breaks of lower zinc concentration appear to refute this trend, but they do suggest a tendency of zinc values to simulate pinch-and-swell occurrences of metal values in vein and other lode deposits.

Lead Concentrations in Stock

Analyses of bulk rock samples suggest that recognizable trace lead patterns exist in the Tres Hermanas stock. Based on the least altered rock samples from the stock, a background value of 33 ppm lead was calculated (table 7).

In fig. 18, two major divisions were made with lead values up to 50 ppm, and lead values over 50 ppm. Nine anomalous areas are recognized (table 9).

Generally, in each of the outlined anomalies, the lead content forms a characteristic pattern. Highest lead concentrations occupy a central location with surrounding samples decreasing in concentration from this central high. Characteristics of the nine anomalies follow.

Anomaly L-1: This anomaly has three samples with lead content above 50 ppm. The highest lead concentration occurs in sample 58 (299 ppm). It also contains the highest concentration of trace element lead found in the stock. Range of lead concentrations for the anomaly is from 47 to **299 ppm. Trend of the anomaly is generally northeastward.**

Anomaly L-2: **This anomalous area has at least 4 samples with lead concentrations above 50 ppm. The overall range of lead concentration is from 33 ppm to 70 ppm.**

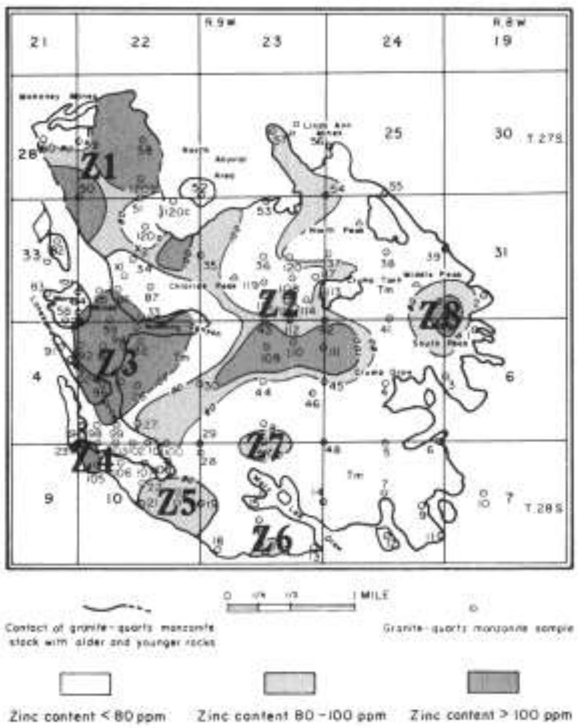

FIGURE 17—*Sketch map of geochemical anomalies of zinc within the Tres Hermanas stock.*

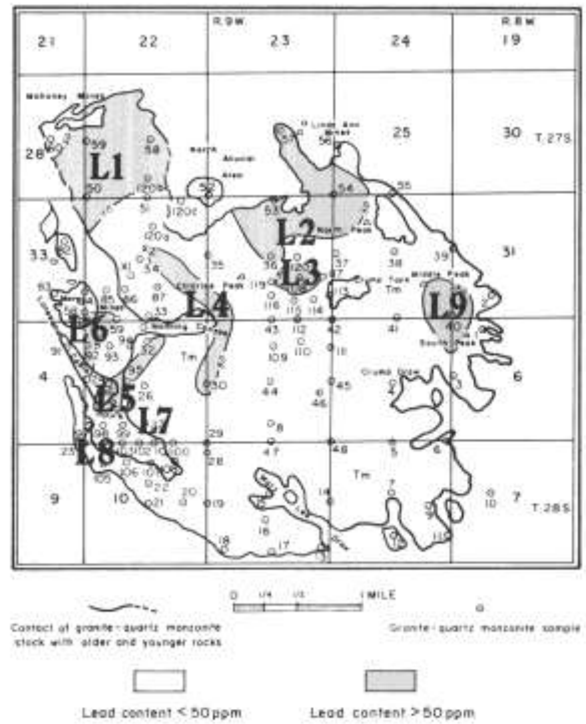

FIGURE 18—*Sketch map of geochemical anomalies of lead within the Tres Hermanas stock.*

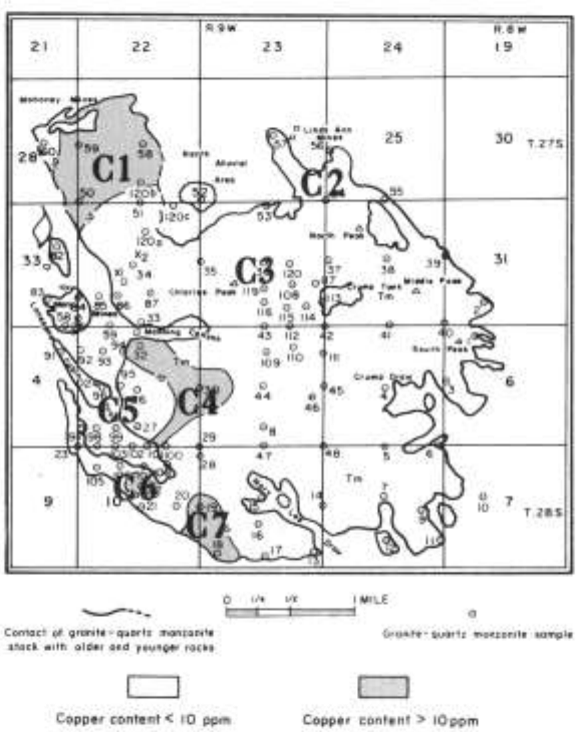

FIGURE 19—*Sketch map of geochemical anomalies of copper within the Tres Hermanas stock.*

A distinctive trend within this anomaly is not readily apparent, although an eastward increase toward sample 54 is suggested. Alluvium bounds the anomaly on the north and Paleozoic rocks on the northeast.

Anomaly L-3: Eleven samples constitute the small anomaly in the north-central part of the intrusive. Range of lead values is from 35 ppm to 228 ppm. The one high sample of 228 ppm lead is supported by 11 samples each of which has more than 33 ppm lead. The pattern shows a consistently increasing lead content toward the high sample. Based on the lead values from both the specific and related samples the anomaly has a northwesterly trend.

Anomaly L-4: A crescent-shaped anomaly consisting of 3 specific samples trends across Manning Canyon, and has a range of 41 to 50 ppm lead. The anomaly is based on three samples of more than 33 ppm lead, with a range from 41 to 50 ppm lead.

Anomalies L-5, L-6, L-7, and L-8: Grouped together because of their close spatial positions. They are based on 5 specific samples (table 9) with lead concentrations ranging from 32 to 177 ppm with sample 91-4 having the highest lead concentration (177 ppm). All other sample values tend to increase toward it. The anomalies in this part of the stock lie at a lower topographic elevation than those mentioned above. Some approach the contact of the granite-quartz monzonite with the adjacent volcanic rocks.

TABLE 9–*Lead anomalies, specific and related samples, Tres Hermanas stock*

Anomaly No.	Specific samples	Related samples
	(Sample No. followed by lead content, ppm, in parentheses)	
L-1	50 (69), 58 (290), 59 (52)	60 (47), 49 (36)
L-2	53 (66), 54 (70), 57 (52)	56 (34), 55 (36), 37 (38)
L-3	118 (229)	42 (45), 43 (35), 110 (35), 111 (35), 112 (37), 113 (34), 114 (42), 115 (41), 117 (37), 119 (45)
L-4	30 (50), 31 (50), 34 (50)	87 (41)
L-5	32 (55), 96 (61)	21 (35), 22 (35), 23 (38), 24 (41), 25 (45), 27 (46)
L-6	91-4 (177)	33 (35), 44 (35), 90 (35), 91-2 (45)
L-7	101 (50)	91-3 (42), 91-5 (35), 91-7 (35)
L-8	105 (50)	94 (40), 95 (41), 96 (61), 97 (32), 98 (40), 99 (41), 100 (47), 101 (50), 103 (45), 104 (42), 108 (42)
L-9	40 (67)	2 (35), 3 (46), 4 (37), 38 (38), 41 (38)
Not Delineated		5 (42), 14 (42), 45 (32), 47 (42), 48 (49)

Mineralized veins of westerly trend occur directly west of these anomalies.

Anomaly L-9: An anomaly occurs in the east central part of the stock, based on one high sample of lead concentration >50 ppm, and supported by 5 related samples. In the south-central part of the stock 7 samples (undelineated in table 9) constitute a sub-circular anomaly with lead concentrations ranging from 35 ppm to 48 ppm. Anomalies L-1 and L-2, show a rough easterly trend, while other anomalies are less well defined in terms of trend at the lead value selected. At lower lead concentrations, alignments are discernible, as in the case of anomalies L-7, L-4 and the western part of anomaly L-1.

Copper Concentrations in the Stock

A background value for copper of 6 ppm was calculated in the same manner as for zinc and lead. The data are shown in table 10.

High values of copper have not been recognized in the Tres Hermanas stock. The calculated average background value is 6 ppm and the highest copper content analyzed is 19 ppm in the northwest part of the stock.

Anomalies with copper concentrations above 10 ppm are shown in fig. 19. Seven anomalies are indicated in table 10 and on the map.

Anomaly C-1: This westerly trending anomaly is based on 3 specific samples and two related samples. The range of copper concentration in the samples composing this anomaly is from 7 ppm to 19 ppm with sample 50 having the highest.

Anomaly C-2: A small anomaly, based on one specific sample with more than 10 ppm copper and 2 related samples with more than 6 ppm copper, occurs in the northeastern part of the stock. The copper content in the samples ranges from 7 ppm to 10 ppm. The values trend easterly and increase toward the high value at sample locality 54 (10 ppm).

Anomaly C-3: A small anomaly occurs in the center of the stock based on one specific sample and 5 related samples. The range is between 6 and 10 ppm copper.

Anomalies C-4 and C-5: Grouped together. Four specific samples and 15 related samples make up these anomalous areas. The range of copper content in these samples is from 6 ppm to 17 ppm. Copper values in the related samples increase toward the high copper content sample.

Anomalies C-6 and C-7: Directly south of anomaly C-4. Anomaly C-6 is based on one specific sample and two related samples. Anomaly C-7 has 2 specific samples and 2 related samples with over 6 ppm copper content. Range in copper content is from 7 ppm to 14 ppm. Samples show a consistently increasing trend in a southeasterly direction toward the high copper value. Several samples in the southern part of the stock show copper values slightly above background. These range from 6 ppm to 9 ppm copper content. A possible alignment of copper values is suggested in a northerly direction parallel to Lonesome Cabin Draw on the western margin of the Tres Hermanas stock. This

TABLE 10–*Copper anomalies, specific and related samples, Tres Hermanas stock*

Anomaly No.	Specific Samples	Related Samples
	(Sample No. followed by copper content, ppm, in parentheses)	
C-1	50 (19), 58 (17), 59 (13)	49 (8), 60 (7)
C-2	54 (10)	53 (9), 57 (7)
C-3	119 (10)	37 (6), 110 (9), 114 (8), 117 (9), 118 (7)
C-4	30 (13), 32 (17) 101 (10)	26 (4), 33 (6), 34 (8), 35 (7), 84 (6), 85 (7), 86 (9), 87 (5), 91-4 (8), 91-5 (5), 96 (6)
C-5	95 (10)	100 (9), 105 (7), 106 (6), 108 (7),
C-6	22 (13)	20 (7), 13 (9)
C-7	18 (14), 19 (11)	
Not delineated		4 (9), 6 (7), 9 (4), 11 (5), 12 (8)

alignment includes anomalies C-1, C-4, C-5, C-6, and C-7. Further, the highest concentrations in each of these anomalies, comprising samples 50, 32, 95, 101 and 22, are also roughly aligned. Except for minor fluctuations, they increase from the south to the north.

Relation of Anomalies to Petrographic Characteristics

In the petrographic study of thin sections from the stock, special attention was devoted to textures, including unusual textures as granophyric, perthitic, antiperthitic, myrmekitic, grain size and other petrographic features which might be genetically related to the development of anomalous metal concentrations and/or alteration features in the intrusive body. Table 3 summarizes these data. General conclusions are summarized in the following paragraphs.

1) Zinc, lead and copper contents in the stock generally show a tendency to increase with decrease in size of the feldspar phenocrysts to about 1.8 mm. A slight deviation occurs with regard to lead in sample 53.

2) Moderate-sized phenocrysts of about 1.8 mm are generally associated with high concentrations of zinc, lead and copper.

3) Granophyric, perthitic, antiperthitic, and myrmekitic textures, lath-like characteristics of the groundmass feldspar, locally broken-appearance of the feldspar laths, and sieving, corrosion and embayment of feldspars are generally associated with anomalous concentrations of zinc, lead and copper. Increase in amounts of granophyric texture is related to an increase in zinc, lead and copper content in 66 percent, 50 percent and 66 percent of the cases, respectively. These follow the general pattern of trace metal values in the stock and their relationship to intensity of alteration.

4) Bent, twinned and zoned feldspars generally are associated with moderate to high metal anomalies. Concentrations of zinc, lead and copper (ppm) increase with higher potash feldspar content relative to plagioclase. The relationship of quartz to base trace metal content is not clear.

5) The textures cited above as spatially associated with anomalous zinc, lead and copper values do not occur in moderate to abundant amounts in areas lacking anomalies.

Ferromagnesian minerals as biotite, hornblende, pyroxene, magnetite and other accessories are present in areas of anomalous concentrations of zinc, lead and copper. Yet, in areas of high anomalies of lead, zinc and copper in the stock, the ferromagnesian mineral content generally shows a tendency to decrease with increasing concentrations of these metals beyond a certain limit. Hence, the additional trace metal content is apparently related to the alteration of these minerals.

7) Individual ferromagnesian minerals do, however, show certain correlations with concentrations of zinc, lead and copper. Biotite, hornblende, tremolite, diopside, aegirine-augite and magnetite occur commonly with moderate to high concentrations of trace metals. In the case of zinc (>500 ppm) and lead (>200 ppm) mafic minerals higher in the Bowen reaction series seem to occur. For example, hypersthene occurs in samples 91-4, 116, 118 and others where the concentrations of zinc, lead and copper are high. Muscovite is present under moderate alteration conditions with moderate metal concentrations (sample 101, with 74 ppm, 50 ppm and 10 ppm zinc, lead and copper, respectively).

The relationships of other accessories as sphene, zircon and apatite, are not clear, but detailed investigations of these have not been made.

Relation of Concentrations to Altered Areas

As a generalization, alteration patterns and geochemical anomalies are associated in space. Indeed, rock alteration appears to be invariably present in areas of geochemical anomalies. Each metal anomaly has its specific character, i.e., moderate alteration may be accompanied by an anomaly with base-metal content of several hundred ppm, whereas another anomaly with a similar intensity of alteration has a lesser metal content. Thus, although there are general trends, individual deviations do occur in specific anomalies, as cited below.

The relationship of alteration to the concentrations of the individual trace metals and the trends of each type of alteration and associated metal anomalies are shown in figs. 20, 21 and 22 for zinc, lead and copper, respectively.

Zinc concentrations generally decrease with increasing argillic alteration to about 200 ppm except for anomalies Z-1, Z-3, and Z-4. A similar relationship exists for the lead values, except in anomaly L-9 zinc tends to increase with increase in lead content. The anomaly, however, is moderate with a maximum of only 67 ppm lead. Copper values have a less direct relationship to the general patterns of argillic alteration, but spatially there is a relationship.

Sericitic alteration shows a relationship similar to that of argillic alteration with zinc, lead and to a large extent copper. Moderately altered areas show higher metal values than low or more highly altered areas.

Chloritic alteration is widespread although of weak intensity. Zinc concentration generally decreases with increasing chloritic alteration to a certain level for each specific anomaly. Lead and copper exhibit a similar relationship.

Relation of Anomalies to Intruded Rock Units and Mineralized Areas

In general, outlined geochemical anomalies and known ore mineralization within and around the Tres Hermanas stock are closely associated in space.

The lead-zinc Mahoney mines are located north and

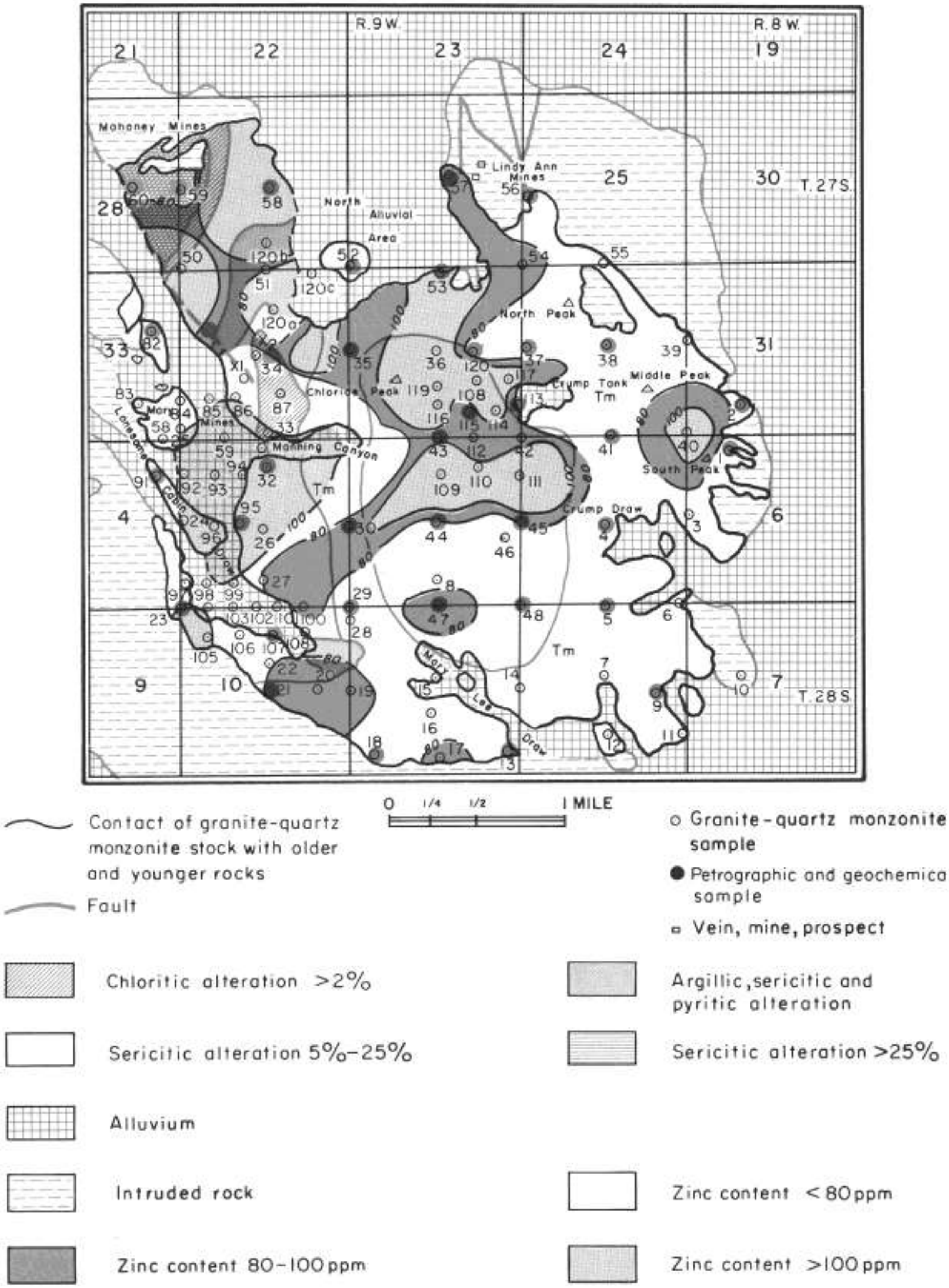

FIGURE 20—*Relationship of alteration to zinc concentration (ppm) within the Tres Hermanas stock.*

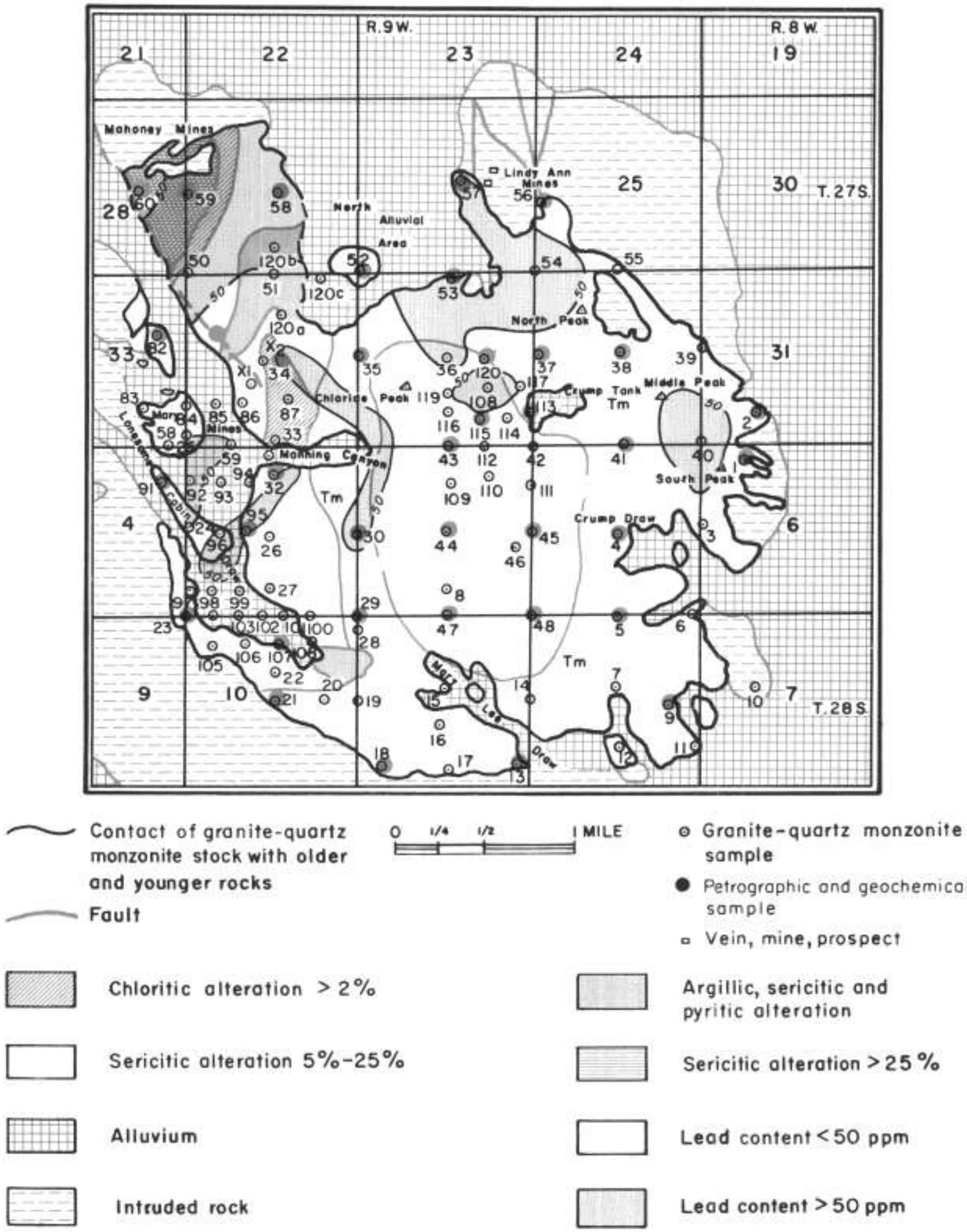

FIGURE 21—*Relationship of alteration to lead concentration (ppm) within the Tres Hermanas stock.*

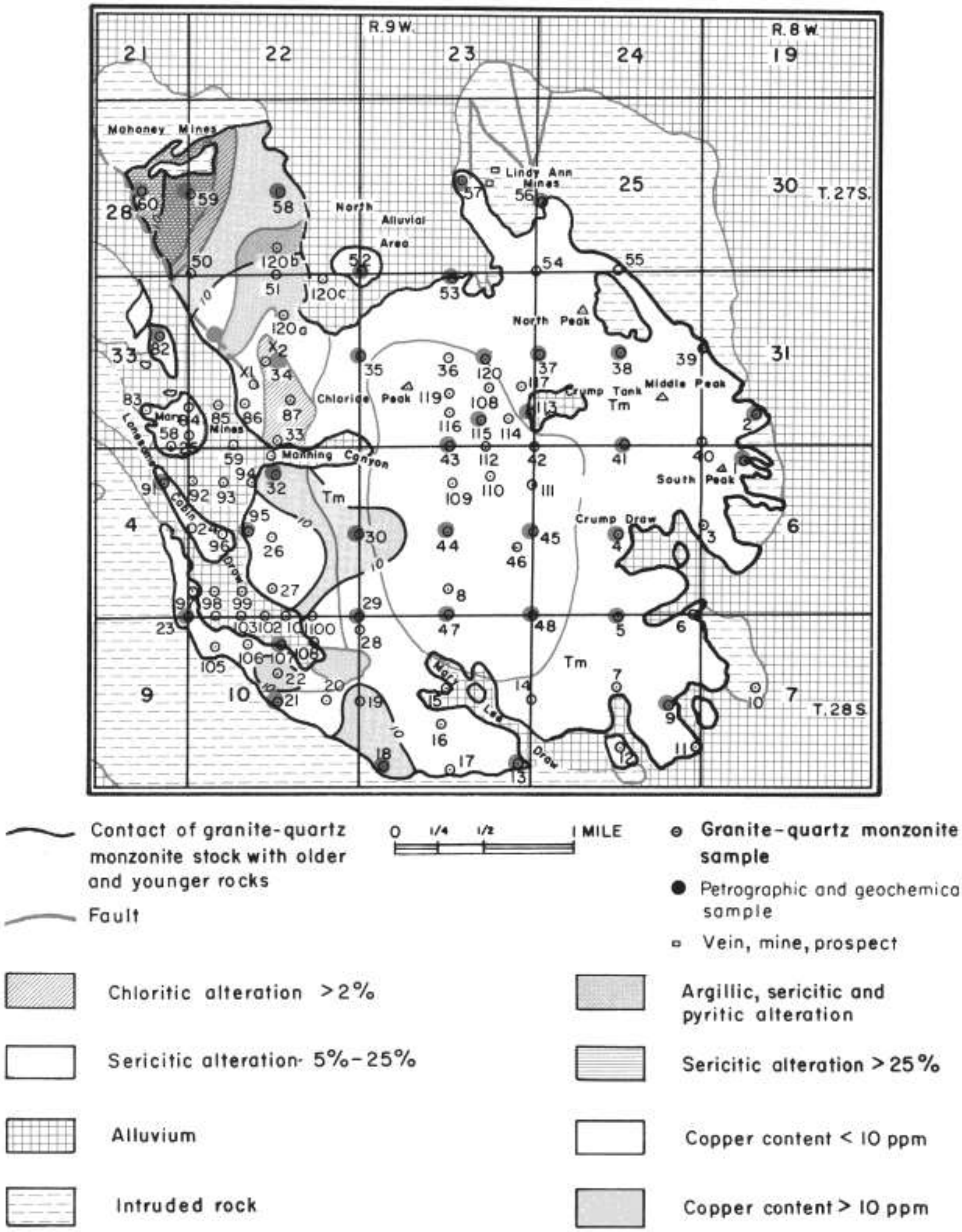

FIGURE 22—*Relationship of alteration to copper concentration (ppm) within the Tres Hermanas stock.*

slightly west of anomalies Z-1, L-1 and C-1. The Lindy Ann group of mines are just northeast of the northeast extent of anomalies Z-2, L-2 and C-2 at the northeastern margin of the stock. Zinc and lead contents consistently increase northeastward (sample 58) whereas copper increases to the southwest (sample 50).

A shaft has been sunk, and several hundred pounds of galena and sphalerite recovered from an intensely pyritized zone within anomalies L-3, C-3 and the southern or lower part of anomaly Z-2, in the central part of the stock. A xenolith is the nearest exposed sedimentary rock. Whether other xenoliths of similar type exist at depth and are affected by the relatively high values of zinc (500 ppm) and lead (228 ppm) associated with these anomalies is not known. Anomalies L-4 and C-4, and a narrow southwestward extension of anomaly Z-2, occur in the granite-quartz monzonite trending across Manning Canyon and adjacent to Lonesome Cabin Draw.

The lead-zinc Marie mine and mines of the Cincinnati vein system in the volcanic rocks on the west-central margins of the stock occur about 700 feet north of anomalies Z-3, L-5, L-6 and C-5. Prospects containing abundant iron and manganese oxides and minor lead, zinc and copper minerals lie west of these mines. Both high zinc and lead values increase westward and occur at lower elevations within the stock in this area. Whether the concentration of the base metals increases at depth, especially near potential Paleozoic host rocks beneath the volcanic cover in this area, is not known.

Anomalies Z-8 and L-9, on the south and east slopes of South and Middle Peaks, are just west of several prospects in the metamorphosed Paleozoic sediments; these prospects contain minor amounts of galena and sphalerite. Xenoliths crop out nearby in the stock. Contiguous Paleozoic sediments are the host rocks for the intrusive body to the east.

Anomalies Z-4, Z-5, Z-6, C-6, C-7, L-7 and L-8 are adjacent to the southwestern border of the stock bounded by volcanic rocks. Zinc values show both easterly and westerly increasing trends in their anomalous concentrations. Lead values increase toward the north; copper concentrations, however, increase toward the south and the border zone. Only in the case of copper do relatively high values occur near the contact zone.

Impure calcareous rocks form a large portion of the sedimentary sequence exposed in a semicircular pattern around the northern part of the stock. The prominent north alluvial area reentrant into the stock has a partly exposed fringe of carbonate rocks. Some of the well exposed carbonate sediments were favorable host rocks for mineralization.

TABLE 11–*Lead and zinc ore shipments from Mahoney mining area, 1915–1959*

(from Griswold, 1961, p. 46)

	Zinc			Lead		Silver	
	Ore Wt. tons	%	Metal tons	%	Metal tons	oz/ton	Metal ozs
1915	169	32.6	55	–			
1916	640	33.7	211.2				
	10	–		42	4.2	5.4	54
1917	383	36.7	141				
	29			26.8	7.75	6.7	194
1918	107	34.9	37.3				
	30			45.7	13.7	6.0	180
1919	–						
1920	41			42.2	17.3	913	381.3
1921-1925							
1926	19			38.6	7.33	7.1	134.9
1927-1942							
1943	62			22.8	14.13	6.9	427.8
1944-1947							
1948	76			9.2	6.99	2.8	212.8
1949-1959	–			–	–	–	–
Total produced	444			71			

A northwest-trending fault bounds anomalies C-1, L-1 and Z-1 on the west. The fault notably extends into anomalies Z-3, L-5, L-6 and C-5. Furthermore, intensely altered rock occurs locally along this zone (samples 107, and others).

West of anomalies Z-3, C-5, L-5 and L-6, which are in an area of moderately altered rocks, mineralization may occur in sedimentary rocks below the volcanic rock cover.

Significantly, the known mining areas are spatially associated with patterns of anomalous zinc, lead and copper concentrations within the stock itself. Also the production figures for lead and zinc shipped from the Mahoney mining area may be significant. Copper production is not listed, either because the production was too low or not recovered by milling. The quantity of zinc is much higher than lead (table 11) with a ratio of 6 to 1. A similar relationship is reflected in the zinc-lead-copper anomalies in the stock. The geochemical zinc concentrations are highest, lead is next and copper shows the least. Possibly, by coincidence only, a comparison of the ratios of highest geochemical concentration of zinc to lead to copper in the stock is 6.5/1/0.1 compared to mine production figures of zinc to lead to copper of 6/1/0, respectively.

GENETIC IMPLICATIONS OF ANOMALIES AROUND THE TRES HERMANAS STOCK

Anomalies of zinc, lead and copper show definite spatial associations with, and occur near the mineralized areas around the stock. These anomalies mainly trend toward or parallel known mineralized zones. Zinc and lead anomalies show a fairly congruent relationship in their spatial distribution; the relationship between copper anomalies and these two metals is less obvious.

Petrographic characteristics of the granite-quartz monzonite demonstrate that zinc, lead and copper anomalies in the stock have a tendency to increase with decrease in size of feldspar phenocrysts. Granophyric texture varies in amount and where moderately abundant is generally associated with greater concentrations of trace metals.

Potash feldspar content increases with increasing trace metal content. The unaltered ferromagnesian mineral content on the other hand shows an increase with decreasing trace metal content, except for copper. The latter shows no direct or indirect relationship.

Certain other petrographic features appear to relate to a late crystallization phase in the intrusive: larger phenocrysts, the relatively characteristic association of high-order pyrogenic minerals as hypersthene, twinning of orthoclase feldspar, normal zoning of plagioclase, bending and embayment of feldspars, and relict magnetite in sodic feldspar. These features are associated with a greater trace-metal content in the intrusive.

Higher trace-element content occurs in the deeper interior portions of the stock. Conversely, peaks and ridges of this area generally show lower trace-element content of zinc, lead and copper. Whether a true "peripheral shell" and "interior phase" (Mackin, 1954) exists in this stock is not known. The sampling grid used, eliminated bias on sample locations; hence, separate sampling and rock type mapping was not attempted.

Argillic, sericitic, chloritic, pyritic, and epidotitic alterations are present in the stock. Rock alteration appears to be almost invariably associated with geochemical anomalies of zinc, lead and copper (figs. 20, 21, and 22). Argillic, sericitic and chloritic alteration intensities were determined microscopically. All 3 are generally related to anomalous trace metal content in a direct relationship. Based on moderate sericitic and weak chloritic alteration in areas of moderate (5 percent) ferromagnesian content, the relationship between trace metal concentration and ferromagnesian content may depend to a large extent on the type and degree of alteration.

Some authors (Griffitts and Nakagawa, 1960; Mantei, Bolter and Al-Shaieb, 1970) argue that high trace-element content in stocks near mineralized zones is the result of leakage from these zones. This possibility does not appear to be the case for the Tres Hermanas stock. Here high trace metal anomalies occur in the northwestern portion of the stock, i.e., south of the Mahoney mining area, in the outcrops of the Lonesome Cabin Draw, south of Marie mine of the Cincinnati vein system, at the junction of the Manning Canyon and the Lonesome Cabin Draw and in section 35. The possibility that these anomalous areas resulted from penetration by mineralizing solutions from foci in the ore zones can be conceded. Yet, such a possibility is unacceptable for other anomalous areas such as near the Lindy Ann mining area, where no significant anomaly is indicated. High trace metal anomalies in the stock interior in Manning Canyon and in section 35, are separated from mineralized and productive areas by low trace-metal values. Even near the Mahoney mining area, intrusive rock samples close to the mines have lower trace-metal contents than those farther away. Finally, other alteration zones and anomalies are isolated and have individual local trends unrelated to known mineralized zones.

Spatial relationships of zinc, lead and copper anomalies in the stock to mineralized areas suggest a possible genetic relationship. While the anomalies in the central part of the stock have no known associated mineralized bodies, such possible mineralized zones may have existed in now eroded and removed cover rock or xenoliths.

Migration of ore metals into the sedimentary rocks around the stock must have occurred through openings, both inherent in the rocks and those induced by the force of intrusion. The relative concentrations within the stock as shown by the anomalies (figs. 17, 18 and 19) suggests potential routes of the probably diffuse plumbing system for the lead-zinc and minor copper mineralization around the stock.

Trace-metal concentration to rock alteration could have resulted from a hydrothermal source, as is supported by the almost consistent association of anomalous metal concentration with alteration, of at least a moderate intensity. Chloritic alteration plus primary ferromagnesian mineral content in altered areas equals, in general, the ferromagnesian mineral content in the unaltered areas. Joints in the stock may have locally provided channelways for the fluids. Except in the altered areas, joints in most of the stock do not show alteration along their walls.

The vein and manto-type mineral deposits suggest that these bodies probably formed from fluids under conditions of moderate temperature and pressure.

Griswold (1961) suggests that the ore mineralization of the district originated from deep-seated differentiation products of the granite-quartz monzonite stock released over several different periods, ranging from the emplacement of the stock to the time basic dikes were emplaced after stock consolidation.

At least two origins for the geochemical anomalies within the stock seem applicable: 1) a deuteric or late magmatic phase of the stock with release, mobilization and redeposition of trace metals in the stock, and 2) a hydrothermal phase in which the consolidated stock was locally sericitized, argillized, chloritized, epidotized and pyritized. Argillic alteration was most widespread and affected the rock most. Sericitic alteration was next most abundant, with chloritic alteration being the least abundant.

In the early deuteric stage, fluids carrying metals may have directly escaped from the intrusive into susceptible sedimentary rocks to form contact metasomatic iron deposits (Griswold, 1961). During one or more later hydrothermal stages, trace-metal content generally increased in the altered zones. The plumbing system was diffuse, possibly joint controlled. Egress of the fluids from the stock into the sedimentary rocks probably was through faults and/or joints into susceptible and favorable structural and stratigraphic environments of deposition. Manto-like bodies and vein replacement lode deposits were the end products.

GEOCHEMICAL PATTERNS IN NORTH ALLUVIAL AREA

An alluvium-covered area of 2 square miles forms a conspicuous topographic re-entry into the northern part of the stock. Because of its position between two mineralized areas, it was selected for a geochemical investigation of heavy metals in the alluvial sands and gravels. Six main washes drain this northern area of the Tres Hermanas Mountains. These washes were sampled (fig. 4).

A few rhyolite and latite dikes, and small inliers of limestone and granite-quartz monzonite crop out in the area. A small hill of granite-quartz monzonite occurs near the southwestern corner of the alluvial area, at sample 52. Small outcrops of igneous rock also occur near sample 64. Exposed limestones are impure, have a high silica content, and appear to have been intruded by numerous small dikes of rhyolite and latite. At one locality limestone occurs as a xenolith (sample 62).

Atomic absorption analytical results were obtained for zinc, lead and copper from the —120 mesh fraction of the 22 alluvial samples which were collected.

Zinc Anomalies

Zinc concentrations in the alluvium are shown in table 6 and plotted in fig. 23 with a contour interval of 50 ppm. Contents range from 75 ppm to 300 ppm with the highest near samples 63 and 70. Sample 63 is near a small spur of limestone and rhyolite in a contact zone with quartz monzonite. Sample 70 is west of the Lindy Ann mining area near the stock-limestone contact.

The higher zinc concentrations are nearer the intrusive-sedimentary rock contacts and tend to increase upslope toward the stock.

Lead Anomalies

Lead contents in the alluvial area, as shown in table 6, range from <20 ppm to 100 ppm. The distribution of lead content is shown by contours with a 10 ppm interval in fig. 24.

The highest lead content is at sample site 62, coincident with a high zinc value. This site, with both limestone and rhyolite exposed, is fairly near the intrusive contact of the stock with sedimentary rocks.

The area near this sample may have potential for both zinc and lead mineralization, as may location 70. Additional detailed sampling is recommended to determine the lead-zinc mineralization potential in this area.

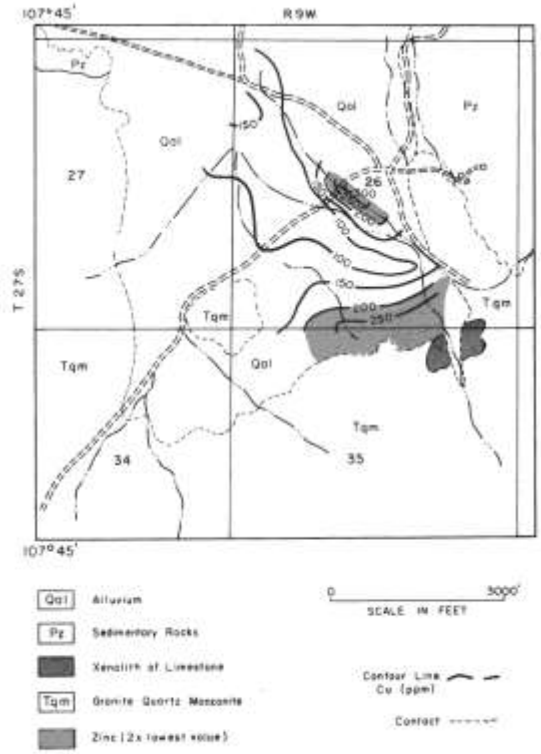

FIGURE 23—*Distribution of zinc (ppm) in alluvial area.*

Copper Anomalies

Copper concentrations in the alluvial area are shown in table 6 and plotted in fig. 25 with a contour interval of 1 ppm. Copper contents are even lower in this area than in the sampled bedrock localities. Copper concentration is not coincident with that of zinc and lead, a feature also noted in the stock.

Copper concentrations greater than 15 ppm occur at sample sites 63, 69, 73a and 78. The proximity of igneous-sedimentary rock contacts and outcrops of rhyolite and limestone are equally significant for copper as for zinc and lead. The projection of the trend of the highest copper levels in the stock intersects the southwest part of the north alluvial area in the vicinity of the higher copper levels in the alluvium. This intersection suggests a possible genetic relationship between copper in the stock and that released by weathering and erosion into the alluvium of this area. The source for the latter must be nearby.

Finally, zinc, lead and copper ratios for the alluvial area are similar to those in the stock and in the same approximate proportions as the metal values in ores produced from the area.

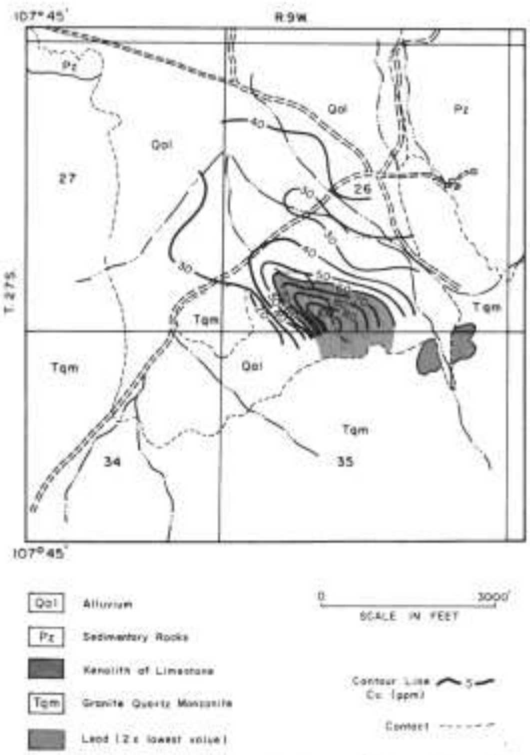

FIGURE 24—*Distribution of lead (ppm) in alluvial area.*

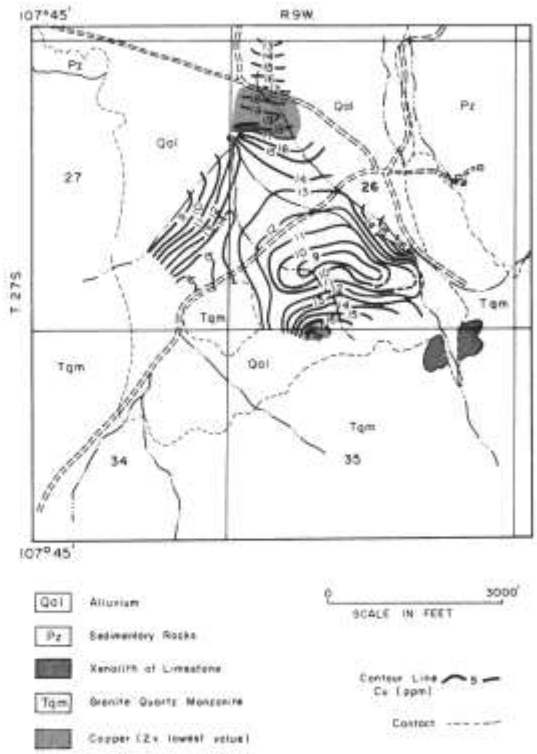

FIGURE 25—*Distribution of copper (ppm) in alluvial area.*

SUMMARY AND CONCLUSIONS

The Tres Hermanas granite-quartz monzonite stock and an adjacent alluvial area were sampled on a half-mile grid system in the stock, and at selected points in the alluvial area. Ninety-nine bulk rock samples and 22 soil samples, respectively, were analyzed by atomic absorption techniques for trace contents of zinc, lead, and copper.

A petrographic study was made of 122 thin sections of the granite-quartz monzonite from analyzed bulk-rock samples and other selected rocks. Thirty-four thin sections, from a grid approximately one mile on a side, were studied for quantitative estimates of potash feldspar, plagioclase feldspar, quartz and ferromagnesian minerals using a Swift Point Counter. Kaolinitic, sericitic and chloritic alteration products were estimated from these thin sections.

Quantitative petrographic and alteration data were used to determine the spatial relationships between those features and anomalies of zinc, lead and copper. Analytical data for metal contents, mineral composition, and alteration intensity were plotted and contoured for graphic comparison.

A major conclusion from these studies is that the anomalies of zinc, lead and copper have similar distributions within the stock, although the copper anomalies are not as sharply defined, nor spatially as closely associated.

While single metal anomalies of zinc, lead and copper do occur as isolated areas in the stock, they have a roughly congruent relationship to each other. Some anomalies of distinct trends and of possible significance to the genesis of ore-grade deposits occur in the northwestern corner of the stock near the Mahoney mining area, in the western part, and in the southwestern part of the stock. A general east-west trend of zinc and lead anomalies in the stock aligns with the prominent and productive Cincinnati vein-system, in Tertiary volcanic rocks. Whether mineralized replacement zones exist at depth is not known because volcanic rocks cover the older sediments; but the probability seems favorable.

Most of the major anomalies of zinc, lead and copper within the stock occur near its margin and in proximity to ore-susceptible formations. A strong possibility exists that ore-bearing fluids migrated toward these more favorable stratigraphic horizons. The plotted results show that many of the geochemical anomalies occur in proximity to known mineralized zones in the country rock.

Major geochemical anomalies in the central part of the stock are located at considerable distance from the exposed sedimentary rock sequence. That a receptive formation once covered the intrusive body in this area is suggested by the many xenoliths and possible roof pendants now present in the stock. Hidden xenoliths may also be present within the stock at depth.

Possibly significant is the ratio of highest concentrations of the heavy metals zinc/lead/copper in the stock, 6.5/1.0/0.1. This ratio is similar to the mine metal production ratio of zinc/lead/copper in the Tres Hermanas district which is 6/1/0. At Searchlight, Nevada ratios of the high geochemical zinc-lead-copper anomalies also accord with the production ratios of these same metals. If these observations have geologic significance, then high trace contents of metals in a statistically sampled stock could be indicators of the metal ratio of potential ore production from mineralized areas around an intrusive body. A corollary follows that, if the quantity of one metal produced from the district is known, then the quantity of other metals in the district might be predicted by ratios of metals in the strongest anomalies in the stock.

Based on petrographic data, higher concentrations of zinc, lead and copper are associated with rocks having greater potash-feldspar content relative to plagioclase. Phenocryst sizes in these cases were moderate (1.8 mm) as was the prevalence of granophyric texture. Ferromagnesian minerals decrease with increasing concentrations of zinc and lead. Copper shows neither direct nor indirect relationships to ferromagnesian minerals.

Rock alteration appears to be invariably associated with anomalous concentrations of zinc, lead and copper. Yet, extremely high concentrations of lead and zinc (i.e., over 150 ppm for lead, and over 200 ppm for zinc) are correlated with only moderately intense argillic alteration, moderate sericitic alteration and weak chloritic alteration. Pyritic alteration occurs in areas of relatively high lead-zinc anomalies. Relatively intense rock alteration is commonly associated with moderately anomalous metal concentrations, i.e., 90 to 100 ppm for zinc, 50 to 60 ppm for lead and 10 to 13 ppm for copper.

To summarize, in the Tres Hermanas granite-quartz monzonite stock, recognizable spatial relationships exist between geochemical anomalies of zinc, lead and copper and also with regard to:

a) surrounding sedimentary rocks
b) known mineralized areas
c) petrographic characteristics of size of feldspar phenocrysts, granophyric texture, feldspar ratios and the amount of ferromagnesian minerals
d) rock alteration by argillization, sericitization, pyritization and chloritization.

In the north alluvial area, zinc and lead concentrations in the soils generally coincide; and high levels occur in the mid-eastern side of the area for zinc, and the southern side of the alluvial area for lead, near the presumed sedimentary-intrusive contact. Copper, which is low (maximum 20 ppm), has higher levels downstream in the alluvial area, and does not coincide with the patterns for lead and zinc. The ratio of highest zinc/lead/copper concentrations in the alluvial area is 3/1/0.2. Potential mineralized zones for zinc in the bedrock are in the southern and northeastern parts of the alluvial area, and for lead in the southern part both near the contact. The prospects for significant copper mineralization are not as favorable as for lead and zinc.

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