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GEOLOGY AND BASE METAL MINERALIZATION OF THE SOUTHERN JARILLA MOUNTAINS OTERO COUNTY, NEW MEXICO

by

R. E. BEANE
Geoscience Dept., New Mexico Inst. Min. and Tech., Socorro, New Mexico 87801

L. E. JARAMILLO C.
Ingeomiñas, Apdo aéreo 1584, Bucaramanga, Colombia, S.A.

M. S. BLOOM
Bear Creek Mining Co., Tucson, Arizona 85707

The materials presented in this paper are partial results of a continuing study of the Orogrande District by the senior author and graduate students in the Geoscience Department of the New Mexico Institute of Mining and Technology. Some of the included information is drawn from previous reports on the area by Kelley (1949), Seager (1961), Schmidt (1962), and Schmidt and Craddock (1964). The New Mexico State Bureau of Mines and Mineral Resources has been exceedingly generous in its material and financial support of the project. One of the theses contributing to this communication (MSB) received financial assistance from the New Mexico Geological Society as well as the Society of Sigma Xi. Another current MS thesis project in the district by Donald Strachan, involving construction of a composite stratigraphic section for the Jarilla Mountains, has also received financial aid from the New Mexico Geological Society; preliminary results of this project are included herein.

The Jarilla Mountains are a prominent interior desert range rising sharply from the flat surface of the Tularosa Valley, midway between Alamogordo, New Mexico and El Paso, Texas. The mountain range is approximately 4 mi wide in an east-west direction and 10 mi in north-south length; maximum relief is about 1,200 ft and averages about 600 ft. Steep, rugged hills encompass interior valleys bordered by alluvial fans and pediment surfaces. Access to the area is provided by a network of unimproved roads which connect to U.S. Highway 54 to the east; access from the west is restricted by White Sands Missile Range.

The Orogrande mining district, located within the range, is presently inactive, most production having taken place from the late 1800's to about 1930. Total production from the district is valued at about $2.5 million. About $0.5 million was obtained from both gold and iron; the remaining 60% was almost entirely from copper and lead production of 3,200 tons and 700 tons respectively (Schmidt, 1962).

The Jarilla Mountains lie near the intersection of a northerly trending, linear group of mid-Tertiary intrusives, which extend from Colorado to Texas, and the Texas lineament (cf., Schmitt, 1966). The mountains are underlain by a complex suite of igneous rocks intruded into Paleozoic sedimentary rocks; general geologic relations are shown schematically in Figure 1. The southern part of the range contains a large intrusive mass of monzonitic affinity which surrounds a central core of granodiorite. Field relations indicate that the monzonitic intrusives are younger than the granodiorite, which occurs in both the central part and in the extreme northwest corner of the mountains. Monzonite also crosscuts a small body of intrusive quartz latite near the southeastern corner of the main monzonite mass. Direct geologic relationships be

tween the granodiorite and quartz latite have not been observed. Fringing the southern and eastern sides of the monzonite are upwarped Pennsylvanian carbonate rocks, which have undergone varying degrees of contact metamorphism adjacent to the intrusive. The general structural setting of the range thus appears to indicate forceful intrusion of the monzonite, particularly at the southern end. In detail, however, the monzonite shows evidence of emplacement by stoping, with numerous dikes and sills filling fractures in adjacent limestone. Several isolated blocks of metamorphosed sedimentary rocks in the monzonite may represent either roof pendants, or xenoliths which have not been extensively displaced from the attitude of surrounding sedimentary wall rocks.

A large number of dikes and sills cut the larger intrusive masses as well as the sedimentary rocks throughout the mountain range. With the exception of several andesitic dikes, which constitute a post-mineral igneous event, most of the smaller intrusives are of essentially the same rock types as the larger masses in the district. Although field relations permit many of the dikes and sills to be traced to monzonitic parentage, alteration and isolation leave the source of others open to question at the present time.

In the southern part of the mountains, granodiorite is a dark gray, massive, fine- to medium-grained rock consisting chiefly of plagioclase (An_{65}, An_{08}), 10 to 30 percent orthoclase, 5 to 15 percent iron-rich biotite, 4 to 8 percent hornblende, 5 to 20 percent quartz, and a few percent augite, plus accessory magnetite, pyrite, epidote, apatite, and sphene. K-feldspar increases close to contacts with the monzonite, whereas adjacent to metasediments, biotite is nearly absent and hornblende content increases dramatically. Euhedral plagioclase crystals normally exhibit a 60 percent anorthite component but have a noticeable rim of lighter-colored albite (An_{08}). Quartz and orthoclase appear in anhedral grains interstitial to plagioclase crystals. Hornblende, which sometimes rims and replaces augite, is in turn replaced by biotite. Pyrite and magnetite replace and envelop hornblende and biotite. At the extreme southern end of the central granodiorite body, and on the western edge of the granodiorite at the northwestern corner of the range, two small outcrops of a medium-grained leucocratic facies grade laterally into normal biotite granodiorite. This facies, which occurs in the vicinity of calc-silicate skarns, appears to be a late stage of the granodiorite.

Along the southeasterly margin of the mountains, a body of intrusive quartz latite occurs in contact with the main monzonitic body. The white to pale-pink quartz latite is almost entirely aphanitic, although locally white plagioclase (An_{23}) phenocrysts up to 3 mm in length are found imbedded in the aphanitic groundmass of quartz and K-feldspar. There is a con-
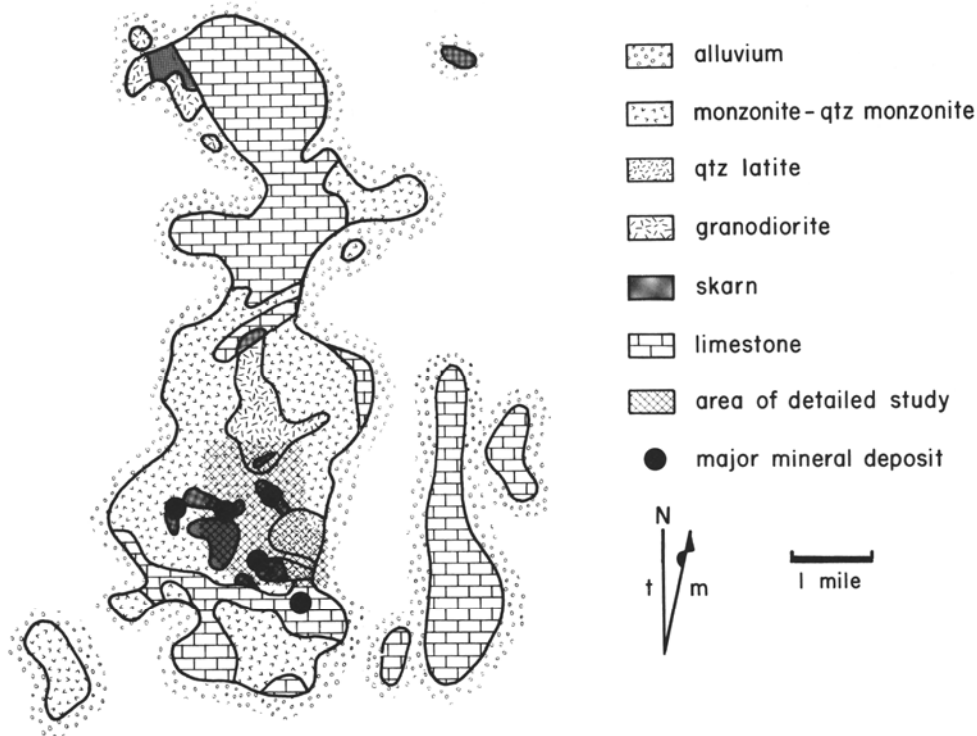
Figure 1. Generalized geologic map of the Jarilla Mountains, compiled, in part, from Seager (1961), Schmidt (1962), and Schmidt and Craddock (1964). Hachured area corresponds to detailed work illustrated in Figure 2.

spicuous absence of mafic minerals, but disseminated pyrite, largely altered to limonite, is common. Sedimentary rocks in contact with quartz latite do not show evidence of contact metamorphism.

Monzonitic rocks are the most abundant igneous material in the southern Jarilla Mountains. A hornblende-rich monzonite facies occurs in large masses in an area about 5 mi long and about 4 mi wide. This rock type, which shows considerable variation in composition areally, intrudes both granodiorite and quartz latite and shows typical intrusive relations such as chilled margins, sheeting parallel to contacts, and apophyses into the intruded material. A second orthoclase quartz monzonite facies forms a large mass along the eastern edge of the north-central part of the mountains and several smaller elongate and dikelike bodies in the southern half of the range.

Fresh hornblende monzonite, normally at a distance from the contacts, typically contains 30 to 40 percent plagioclase, 35 to 40 percent orthoclase, up to 10 percent hornblende, 5 to 10 percent quartz, and accessory biotite, apatite, sphene, and zircon. Plagioclase phenocrysts, up to several millimeters in length, are continuously zoned, becoming more sodic toward the rims (An_{35} outward to An_{15}); the average anorthite component is 30 percent. Potassium feldspar and quartz form the groundmass of the porphyritic rock. Prismatic phenocrysts of hornblende show pale green to pale brown pleochroism and are commonly rimmed by biotite and chlorite. Adjacent to granodiorite, hornblende is less abundant and quartz increases to 20 percent. In restricted areas, hornblende monzonite may show abundant biotite or engulfed, anhedral eyes of quartz.

Orthoclase quartz monzonite contains about 40 percent orthoclase, 10 to 20 percent quartz, 20 to 40 percent plagioclase, 5 to 15 percent hornblende, and accessory biotite, epidote and sphene. Conspicuous orthoclase phenocrysts several centimeters in length and clear quartz eyes each make up

less than 10 percent of the rock; the remainder of these two components occur in the matrix. Plagioclase feldspar is represented by euhedral to anhedral phenocrysts, distinctly smaller in size than the orthoclase phenocrysts. The plagioclase is about An_{20} overall, but is strongly zoned from calcic cores to sodic rims which are occasionally replaced by sericite and clay. Hornblende phenocrysts are extensively replaced by epidote, calcite, and sphene with attendant pyrite and magnetite grains.

Several dikes of andesitic and diabasic composition cut both the hornblende monzonite and sediments in the southern Jarillas. These dikes, which commonly show strong propylitization, are localized along joints in the host rocks and are probably related to extrusive basalt which forms a restricted outcrop peripheral to the northeastern end of the mountain range.

A biotite concentrate from the granodiorite has been dated at 47.1 ± 1.8 m.y. using the potassium-argon method. Radiometric age dates for the monzonite and quartz latite are not currently available. Geologic relations do not permit a relative age relationship to be established between the granodiorite and quartz latite, although both of these are older than the monzonite. Nevertheless, some tentative suggestions can be made regarding intrusive affinities by means of normative mineral compositions calculated from approximately 250 whole rock analyses. Considerations of eutectic melting relations in the system anorthite-albite-orthoclase-quartz (Ehlers, 1972) indicates that the three intrusive types would be cogenetic only if the plagioclase in the last-forming monzonite contained no anorthite component or the confining pressure were on the

order of tens of kilobars or both. Neither of these requirements are in agreement with petrologic and geologic observations. Consequently we suggest that the granodiorite and latite were derived from the same source, with the latter rock type postdating the former; hornblende monzonite intrudes both of these rock types and was generated from a separate magma.

Two distinctly different fracture orientations are exhibited by intrusive rocks in the Jarilla Mountains. Both the granodiorite and latite are dominated by steeply dipping fractures trending N 5° E with a conjugate set oriented N 50 to 55° E. The monzonite, on the other hand, is characterized by a near vertical joint set with a N 34° E trend and a S 85° E conjugate; this fracture pattern is also weakly superimposed on the granodiorite. These data support the earlier interpretation of igneous intrusive affinities, i.e., that the granodiorite and latite are genetically related, and that the monzonite postdates both. This difference in fracture orientations is occasionally reflected by late andesite dikes, which change strike at contacts between the monzonite and latite.

Sedimentary rocks which crop out in the Jarilla Mountains are reported to range in age from Middle Pennsylvanian to Early Permian (Seager, 1961; Schmidt, 1962). The northern part of the range contains approximately 800 ft of argillaceous or cherty limestone and shale of the Permian Hueco Formation. Also included in this unit are interbeds of mudstone, generally about 50 ft thick, which represent tongues of the Abo Formation. These rocks grade southward, and downward stratigraphically, into 1,000 to 1,500 ft of limestone with lesser amounts of mudstone, sandstone, and conglomerate corresponding to Lower Permian Laborcita Formation (Bursum equivalent) and Upper Pennsylvanian Panther Seep Formation (Holder equivalent). A thin limestone pebble conglomerate containing Wolfcampian fusulinids (Schmidt and Craddock, 1964) serves to place the Pennsylvanian-Permian boundary somewhere in the lower one-third of this sequence, which comprises a large part of the range.

The sedimentary units in the northern half of the Jarillas generally dip north-northeast about 20 degrees or less, although structural elements have locally produced greater distortion. These same units wrap around the eastern flank of the mountains, forming hogbacks which dip steeply away from the central intrusive mass. About 50 percent of the surface outcrop at the southern end of the range consists of the Middle Pennsylvanian Gobbler Formation. This unit, which is made up chiefly of cherty limestone, is between 1,000 and 1,500 ft thick, and is separated from the Laborcita by about 400 ft of shale, argillaceous limestone, and feldspathic sandstone of the Beeman (?) Formation. Middle Pennsylvanian sedimentary rocks have been extensively metamorphosed by the hornblende monzonite intrusive, and the northernmost occurrences consist chiefly of xenoliths and roof pendants of skarn material. Current attempts at reconstructing a composite stratigraphic section for the Jarilla Mountains suggest a sedimentary thickness of 4,000 to 5,000 ft in outcrop.

The Plymouth Oil Company test well a few miles north of he Jarillas showed that the Permian Hueco is overlain by bout 800 ft of limestone, mudstone, and gypsum of the Yeso Formation, which does not crop out in the range (Kottlowski, 963). This well and others nearby indicate about 1,000 ft of Ordovician El Paso Limestone and Montoya Dolomite, Silurian usselman Dolomite, and Mississippian Rancheria Formation limestone) lie under cover in the area. Kottlowski (1963) also suggested that a few feet of Devonian Percha Shale may sep-

arate the Fusselman and Rancheria, but this unit was generally eroded as a result of Late Devonian uplift in the region. Lower Paleozoic units have not been reported to crop out in the Jarilla Mountains, but examination of skarn mineralogy indicates that metamorphic equivalents of Fusselman (?) or Montoya dolomites (?) or both may be represented in the skarns immediately south of the central granodiorite body.

Contact metamorphism of sedimentary rocks to skarns is extensively developed adjacent to igneous contacts. Three varieties of skarn are recognized: 1) widespread pyroxene-scapolite-garnet peripheral to granodiorite intrusives, 2) epidote-garnet-calcite of limited extent immediately adjacent to contacts of monzonite porphyry with limestone, and 3) a more complex pyroxene-scapolite-garnet-epidote-calcite assemblage zoned about dikes which are spatially associated with grandodiorite, but are of uncertain genetic heritage. Contact metamorphic effects are more extensive around the granodiorite than the monzonite, which may be, in part, a result of higher temperatures attending the former intrusive type. Detailed analyses of skarns carried out thus far are restricted to the southern edge of the central granodiorite mass and to metasediments intimately associated with the monzonite in the vicinity of the Ohaysi Valley (Fig. 2).

Schmidt and Craddock (1964, plate 2) provide a detailed description of progressive metamorphism in adjacent limestone and siltstone beds at various distances from a granodiorite contact in the northwest corner of the range. Metasomatic effects appear to be restricted to the immediate vicinity of the intrusive contact; Schmidt (1962) credits the mineralogic variation in siltstone at greater distances from the granodiorite to thermal effects.

In the southern Jarillas, contact effects clearly related to the granodiorite are restricted to a few blocks of skarn engulfed in the intrusive (Fig. 2). At the extreme southern end of the central granodiorite mass, a diopside skarn enclosed within the intrusive is cut by a steeply dipping, east-trending fault. The fault extends for a few tens of feet to the west into the massive granodiorite along a crumpled zone, and finally disappears. This structure may represent offset which occurred while the intruding granodiorite was still partially molten, having only a cooled margin competent enough to support fracturing. If this is the case, the diopsidic skarn is chronologically related to the granodiorite as is east-west faulting in the central part of the range. Skarns in the granodiorite consist of garnet, diopside, and scapolite, the relative masses of each of the phases being apparently related, for the most part, to the original composition of the sedimentary material. One such body contains 85 percent diopside plus 15 percent garnet; in a bulldozer cut along its southern border, a zone of coarse-grained phlogopite is exposed adjacent to pyritized metasiltstone. Another medasedimentary mass in the area is made up of 80 percent diopside plus 15 percent scapolite, similar to the altered metasiltstone described by Schmidt (1962), but containing more diopside. About one mile southwest of these units included in the granodiorite, a number of blocks of originally sedimentary material are surrounded by monzonite; the original rock types appear to have been cherty dolomitic limestone with an interbed of argillaceous siltstone. The calcareous beds were recrystallized into a rock consisting of 80 percent diopside, 10 percent calcite, and 7 percent pyrite; also occurring here are several replacement masses of
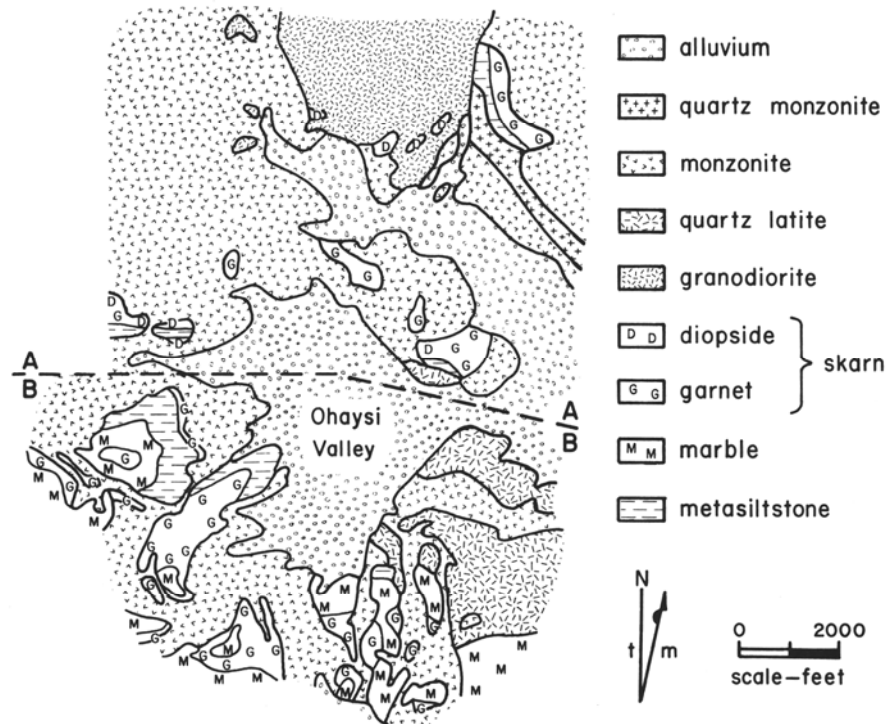
Figure 2. Detailed outcrop pattern of a part of the southern Jarilla Mountains; 2A: Jaramillo C (1973), 2B: Bloom (1975).

magnetite. Sedimentary bedding is still preserved in the metasiltstone, which contains 80 percent quartz, 17 percent muscovite, and minor pyrite.

The abundance of magnesian skarn minerals in the region immediately south of the central granodiorite mass is almost certainly a result of original dolomitic character of the sedimentary rocks, because there is also a large block consisting of 50 percent garnet, 12 percent diopside, and 35 percent calcite in the same area. The presence of material such as this *suggests* that the rocks here did not undergo widespread magnesium metasomatism, but, rather, that the development of diopside depended on the presence of dolomitic sedimentary material. Stratigraphic analyses of the unaltered sedimentary rocks in the Jarilla Mountains and surrounding areas do not indicate the presence of widespread dolomite in either the Pennsylvanian or Lower Permian section, but units of the lower Paleozoic described in drill cores by Kottlowski (1963) and occurring in the adjacent Sacramento Mountains (Pray, 1961) contain cherty and thin-bedded dolomites (Ordovician Montoya Dolomite; Silurian Fusselman Dolomite). The expected contact metamorphic equivalents of such units would be the diopsidic skarn observed in the southern Jarillas, which may have been exposed by a west-northwest trending, westward plunging anticlinal arch about 0.5 mi south of the central granodiorite. This structure is indicated by orientations of sedimentary bedding.

Calc-silicate alteration spatially related to the monzonite in the south-central part of the range shows well developed zonation about the intrusive. The skarns may be divided into two major categories: endoskarns, formed by replacement of the monzonite, and exoskarns, developed in adjacent carbonate rocks. There is a general tendency for exoskarns to be segregated into essentially monomineralic zones arranged systematically away from the monzonite at distances up to

approximately 60 ft parallel to bedding.

Endoskarn is made up almost entirely of epidote plus interstitial calcite resulting from alteration of the calcic component of plagioclase in the monzonite. Actinolitic amphibole (Fe/Mg = 3/2) arid occasional engulfed grains of quartz or garnet may be locally present. This zone is generally only a few feet wide, and grades into monzonite and garnet, toward and away from the intrusive, respectively. Garnet-calcite forms the most extensive zone in the exoskarn. Garnet compositions generally fall within the andradite-grossularite binary solid solution, although minor amounts of spessartite are present; the range in composition observed is $Ad_{60-94}Gr_{0-40}Sp_{1-20}$, with higher Gr-Sp contents near the intrusive, and Ad contents increasing into the metalimestone. Conversely, epidotes generally contain higher Fe:Al ratios moving toward the exoskarn. The garnet zone is transitional into marble away from the intrusive contact; the transition is marked by inclusions of marble in garnet and vice versa. The marble, which is characteristically medium grained, grades laterally outward into unaltered limestone. An irregular zone containing lenses and disseminated needles of wollastonite and diopside may exis between the garnet marble zones. Isolated lenses of these minerals replace, to some extent, chert nodules in the lime stone. Occasional interbeds of siltstone in the dominant, calcic limestone may exhibit extensive alteration to very fine grained epidote in the exoskarn. The cherty character of th limestone more than about 1 mi south of the granodiorit body indicates that they correspond to the Middle Pennsyl vanian Gobbler Formation.

Hydrothermal mineralization in the southern Jarilla Moun tains consists of replacement deposits of base metals, with gol in carbonate rocks adjacent to intrusives, and dissemination

and veinlets of chalcopyrite-pyrite in monzonite. The largest gold-producer in the district (the Nannie Baird Mine) belongs to the first type, occurring largely in a calcite vein which cuts skarn (Seager, 1961); this mine lies south of the present study area so it is not described further here.

Magnetite and hematite are very abundant in the Orogrande district. The major iron deposits (Iron Duke and Cinco de Mayo) occur immediately adjacent to one another in a block of garnet-diopside skarn at the west end of the Ohaysi Valley. Iron ore, in these and similar deposits, is generally made up of magnetite plus minor hematite and subordinate pyrite; copper minerals are notably lacking. Cross-cutting relationships show that the iron oxides postdate development of the calcsilicates. In the zoned skarns peripheral to monzonite contacts, pyrite with or without magnetite is most abundant in the outer part of the garnet zone and merges into specular hematite plus chalcopyrite toward the intrusive. In the diopside-garnet-scapolite skarns, which are generally associated with granodiorite, pyrite and chalcopyrite occur together and hypogene iron oxides are generally absent. Oxidation of this latter type of deposit has produced abundant malachite and chrysocolla with minor chalcocite coatings on pyrite immediately below the oxide zone. Attendant acid alteration of garnet has produced kaolinite, gypsum, jarosite, and limonite. In restricted areas of monzonite adjacent to sulfide bearing skarns, biotite and hornblende are pseudomorphously replaced by pyrite, which also fills fractures up to 1 mm in width. Included in such monzonite are isolated blebs and patches of calcite, garnet, diopside, quartz, and epidote; sericitization of K-feldspar is also observed. The mode of occurrence of the above-mentioned minerals suggests the possibility of local assimilation of skarn by the monzonite intrusive. Also, some patches within the hornblende monzonite contain disseminated pyrite and specularite veinlets not directly related to skarns. In such areas, calcite and garnet veins suggest the presence of a former skarn, which is now eroded.

The hornblende monzonite is generally massive or blocky with fractures about 3 ft apart. Seager (1961) described two domed areas associated with monzonite, which he thought to be intrusive centers; the largest comprises most of the central part of the range, and the other is in the extreme southern end of the range. In the vicinity of this latter dome, a small area of intense shattering occurs in the monzonite. Similar shattered zones appear elsewhere in the monzonite as indicated on Figure 3, but none are continuous over a distance of more than a few hundred yards. They probably represent small stockworks developed along the roof of the stock, which is compatible with the numerous blocks of sedimentary material in the monzonite at the southern end of the range. In some relatively small, isolated areas where the intrusive is thoroughly broken, intense hydrothermal alteration accompanied by metallization is present. Such areas, shown in Figure 3, exhibit the classic porphyry copper alteration types (based on mineral assemblages) described by Lowell and Guilbert (1970).

Potassic alteration has been observed in a single area in the Ohaysi Valley about 1,200 ft east of the Cinco de Mayo Mine. The rock is intensely shattered and veinlets of quartz and K-feldspar permeate the rock. Oxidation is widespread here; limonite and malachite are abundant, but some remnants of original minerals are visible in thin sections. Biotite and sericite are observed replacing plagioclase phenocrysts and, locally,
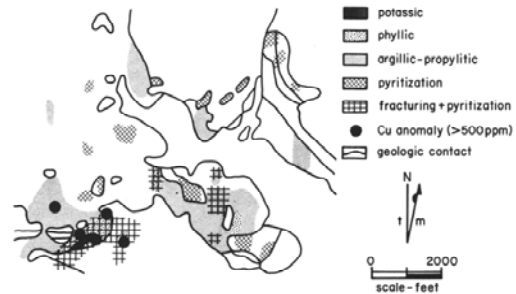

Figure 3. Distribution of mineralization and alteration in monzonite and skarn. Geologic contacts and area covered by the map correspond to Figure 2A. Geology by Jaramillo C (1973).

groundmass feldspars. A light blue, highly birefringent mineral, probably anhydrite, occurs in microveinlets as does a high-iron variety of chlorite (delessite). Magnesian chlorite, probably prochlorite, and leucoxene (?) occur in former hornblende skeletons.

Phyllic alteration, which surrounds and to some extent overlaps the potassic zone, is distinguished by the quartz-sericite assemblage and destruction of mafic minerals. Quartz is present in veinlets and also as "eyes" in the groundmass. Plagioclase phenocrysts are pervasively replaced by fine grained sericite, some of which is oriented parallel to cleavage or twin planes. Sericite also rims quartz veins cutting hornblende skeletons.Minor amounts of clay (probably montmorillonite and kaolinite) frequently accompany sericite, but it is uncertain whether these are a result of argillic alteration or supergene processes. Propylitic alteration is characterized by rimming and replacement of plagioclase and K-feldspar by clay minerals. Epidote and calcite are locally present in plagioclase phenocrysts, and accompany chlorite, rutile, and leucoxene in replacing hornblende. Because of the uncertain origin of argillic material, and because accompanying material commonly exhibits characteristics of propylitic alteration, these two alteration types are combined on Figure 3.

The copper content of hornblende monzonite is normally about a few tens of parts per million, although a few scattered samples, generally in the vicinity of skarns, may show considerable copper enrichment. A few samples of the monzonite analyzed several tenths of a percent copper; these occurrences coincide with zones of intense shattering, and most occur near the potassic alteration described earlier. Molybdenum in these samples is generally less than 2 ppm. Analytical work to date indicates that while characteristics of porphyry-copper-type alteration are present in the monzonite at the southern end of the Jarilla Mountains, copper anomalies in igneous rocks are areally restricted and discontinuous on the surface.

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