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Geology of the San Pedro Mountains,

Santa Fe County, New Mexico

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Abstract

The San Pedro Mountains are one of a chain of four groups of hills in north-central New Mexico. The chain consists of intrusions of monzonite and related porphyry into sedimentary rocks ranging from Pennsylvanian to Eocene. Igneous rocks in the northern two mountain ranges erupted and were reworked to deposit the Espinaso volcanics, which contain definite Oligocene vertebrate fossils.

The San Pedro Mountains are part of a horst in the Tijeras fault system. The Dooley fault crosses the east end of the mountains. Many faults in the mountains are either nearly parallel to the Tijeras fault system or perpendicular to it, other faults radiate from intrusive centers. Five stocks, two laccoliths, and many dikes and sills intruded the sedimentary rocks. The main rock types are monzonite, monzonite porphyry, latite porphyry, and rhyolite porphyry.

Sedimentary rocks have been extensively metamorphosed by the igneous intrusions, yielding tactite, hornfels, and marble.

Important mineral deposits occur in veins and contact metasomatic deposits. The San Pedro mine has been the most important and has produced more than thirteen million pounds of copper since 1900, from a contact-metasomatic deposit in limestone. Lead, zinc, and gold have been produced from mesothermal vein deposits. Gold placers have been among the richest in the State. Nonmetallic deposits include quartz sand, garnet, and limestone. The quartz sand is being developed at present. Water is scarce but available from wells at an average depth of 500 feet.

Introduction

LOCATION, ACCESSIBILITY, AND CLIMATE

The San Pedro Mountains are in the southwestern corner of Santa Fe County, New Mexico, in secs. 13-17, 21-24, and 26-28, T. 12 N®, R. 7 E.; the northern edge of the area lies partly within the Ortiz Mine Grant and entirely within the New Placers mining district. The mountains lie one-half mile southeast of Golden, which is 32 miles by paved road northeast of Albuquerque and 40 miles southwest of Santa Fe.

The most inaccessible parts of the mountains lie no more than one-half mile from narrow dirt roads which connect with State Roads 10 and 344. State Road 344 parallels the mountains about one-half mile to the southwest of them. State Road 10 parallels the mountains one-quarter mile to the west. Good dirt roads lead to the mines; however, they are apt to be slippery after the summer rains and in the winter when the snow partly thaws during the daytime.

The climate is semiarid and somewhat cooler than Albuquerque. The temperature seldom reaches 90 degrees in the summer, and snow commonly lies on the northern sides of the mountains from December to March. The annual precipitation is generally 16 to 20 inches, about half of which is snow. The remaining precipitation comes mostly in late July and early August as sudden afternoon cloudbursts. It may rain as much as an inch during one of these cloudbursts.

TOPOGRAPHY AND DRAINAGE

The San Pedro Mountains are about four miles long in an easterly direction and as much as two miles wide. They are dominated by two eminences, Oro Quay Peak and San Pedro Mountain. These peaks reach altitudes of about 8200 feet, rising 1300 feet above the surrounding pediment surfaces. The slopes surrounding the mountains are similar in nature and origin to those around the Ortiz Mountains, a few miles to the north, where they were termed a conoplain by Ogilvie (1905, p. 28) (pl. 1).

The San Pedro Mountains are part of a chain consisting of four groups of mountains which are aligned in a northerly direction. From north to south they are Los Cerrillos, Ortiz Mountains, San Pedro Mountains, and South Mountain.

VEGETATION AND ANIMAL LIFE

The mountains are covered with piñon and juniper trees, which are sparse on the southern slopes and rocky places and thick on the northern slopes. In favorable places there are a few ponderosa pines, and scrub oak forms thickets in some valleys and on steep and rocky slopes. A few spruce trees grow on the high peaks. On the southern sides of the mountains desert plants, such as yucca and various cacti, are common. In addition there are many varieties of thorny bushes.

Deer and rabbits are abundant, and bobcat tracks are frequent in the snow in winter. Field mice and packrat nests are common. Porcupines may be seen occasionally, and their quills and droppings indicate that they often sleep in abandoned mine tunnels. Unfortunately, rattlesnakes are numerous and an ever-present danger in the summer.

SCOPE AND PURPOSE OF WORK

The geology was mapped on enlarged aerial photographs at a scale of about 3.5 inches to one mile in order adequately to depict the considerable geologic detail. The mineral deposits were examined briefly during the course of mapping. Twenty thinsections of igneous rocks were studied to determine the rock types, al-though detailed petrographic studies were not made.

ACKNOWLEDGMENTS

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Geological Survey permitted use of their equipment during preparation of the maps. Financial aid from the New Mexico Geological Society is greatly appreciated. I wish to thank Mr. James D. Knauer and Mr. Richard F. Atkinson for their assistance in preparation of maps, and Sherman P. Marsh for use of his crystal drawings.

PREVIOUS INVESTIGATIONS

Although many authors have mentioned the general geology, history, and production of the district, there have been very few thorough geological investigations of this area. Until this report, only two generalized maps (Read et al., 1944, and Smith et al., 1945) had been made of the entire group of mountains.

A number of papers published prior to 1900 deal with the San Pedro mine in a general way. In 1903, M. B. Yung and R. S. McCaffery published a report on the ore deposits of the San Pedro district, including a detailed map of the vicinity of the San Pedro mine, In 1916, Augustus Locke and E. H. Perry prepared a private report to the owners of the San Pedro mine, which contained maps and many suggestions for underground exploration, most of which were successful and at least one of which led to a spectacularly rich stope. During the Second World War the U.S. Geological Survey carried out two investigations which eventually led to an important report on the San Pedro mine (Smith et al., 1945). A plane-table map of the area was prepared and excellent maps of the mine showed the locations of ore bodies. A rather hasty reconnaissance map of the entire group of mountains was prepared on aerial photographs at a scale of 2 inches to one mile. This report was never published. In 1946, apparently without the benefit of the federal report, L. P. Entwistle prepared a private report on the San Pedro mine for the American Smelting and Refining Company. This report contained another excellent plane-table map which differs in some small respects from the Survey map. These four investigations are the most important ones. The only published report is that of Yung and McCaffery, which is inadequate in light of our present knowledge. In addition to the most important general papers on the San Pedro mine, several private reports have been prepared on specific aspects of the mine.

Some very interesting historical articles, referred to under History and Production, have been written on the mining district in general, and a number of important geological papers mention the San Pedro Mountains.

General Geology

SEDIMENTARY ROCKS

General Statement

Igneous intrusions, faulting, and poor exposures in the San Pedro Mountains make it impossible to describe the stratigraphy adequately. Sections may be measured with difficulty in only a few places. In most of the area, the sedimentary rocks have been metamorphosed until their original color and texture have been obliterated.

The best unaltered stratigraphic section of beds equivalent to the San Pedro Formation is in the nearby Hagan basin (Harrison, 1949).

Smith et al. (p. 6) believed that only the Madera Limestone and the Abo Formation appeared in the area, but Dr. V. C. Kelley aided the writer in identifying the San Andres, Ye so, and Abo Formations in these mountains.

Madera Limestone

The Madera Limestone, which is the upper member of the Pennsylvanian Magdalena Group, crops out in the western part of the mountains. The Sandia Formation presumably lies directly on the Precambrian in the subsurface but is not exposed in this area.

The limestone is light to dark gray, coarse to very fine grained, and fossiliferous. Many intervals of 10 feet or less of gray and grayish-green shale separate massive limestone beds. Emerick (1950, p. 18) found that the Madera Limestone is about 1000 feet thick in the vicinity of Golden; Harrison (p. 14) found that it is about 1260 feet thick in the Hagan basin, eight miles west of San Pedro; Reynolds (1954, p. 16) found the thickness to be about 916 feet on Montezuma Mountain, eleven miles west of San Pedro.

In Old Timer Gulch and on San Pedro Mountain, the lime-stone has been extensively metamorphosed to garnet rock. In Old Timer Gulch the garnet rock locally contains magnetite, quartz, specularite, and epidote. Some beds rich in limonite and hematite appear to have been pyritized and later oxidized. On San Pedro

Mountain the garnet rock at places is ore. The mineralogy of these deposits is discussed under Ore Deposits.

Abo Formation

The Permian Abo Formation normally consists of variegated sandstone, shale, shaly sandstone, and siltstone, with some limestone beds. The sandstone is mostly deep red to purple, maroon, and brown. The shale is greenish-gray, red, and brown. At places it grades into siltstone and sandy shale (Harrison, p. 34). Harrison (p. 37) found the thickness of the Abo Formation to be about 900 feet in the Hagan basin, and Reynolds (p. 18) found it was about 970 feet thick at Montezuma Mountain. Approximately this general thickness is also present in the San Pedro Mountains.

In the San Pedro Mountains the Abo Formation covers the central third of the range. It has been considerably metamorphosed and consists of black, white, and gray hornfels together with one bed of arkose in the middle part. A few small patches on the northern and the southern edges of the mountains have the normal color and texture of the unaltered Abo Formation.

The lower contact with the Madera Limestone is taken as the top of the last fossiliferous marine limestone. In the San Pedro Mountains this is represented by a massive garnet bed.

Yeso Formation

The Permian Yeso Formation consists of two members, the lower Meseta Blanca Sandstone and the San Ysidro Member. In the Hagan basin, Harrison (p. 46, 48) found the Meseta Blanca Member to be 73 feet thick and to consist of orange-red very fine-grained sandstone. He found the San Ysidro Member to be 377 feet thick and to consist of dominantly brownish-pink fine- to coarse-grained sandstone.

In the San Pedro Mountains no massive fine-grained sandstone is apparent at the base of the Yeso. Here the Yeso Formation consists of dark-red, brown, and pink sandstone beds, much like Harrison's descriptions of the San Ysidro Member. The Yeso Formation has not been subjected to much metamorphism, but in some areas it appears to have been bleached and is buff to white. The outcrops of the Yeso Formation lie to the east of the Abo Formation. A graphic calculation indicates that the Yeso Formation is about 400 feet thick in the San Pedro area.

San Andres Formation

The Permian San Andres Formation consists of three members, the lower Glorieta Sandstone, a limestone member, and an upper member, which in turn may be divided into a lower sandstone and an upper limestone.

The formation crops out in a narrow north-trending strip in the eastern part of the mountains. Graphic calculation showed the thickness to be about 200 feet.

The San Andres Formation differs somewhat in the San Pedro Mountains and the Hagan basin. The Glorieta is a white, pure, medium-grained, and poorly cemented sandstone in the San Pedro Mountains, as contrasted with a gray sandstone cemented by silica in the Hagan basin (Harrison, p. 55). The San Andres lime-stone member of the Formation in the northern part of the San Pedro Mountains resembles Harrison's description of a yellow to gray limestone which "weathers to a cavernous 'worm-eaten' appearance." In the southern part of the mountains it has been metamorphosed and is massive, finely crystalline, and dolomitic, containing needles of tremolite up to half an inch long. The sandstone of the upper member is mostly covered but appears to be a very sandy gray hornfels. The upper limestone bed of the member is present on the ridge east of the Silica mine, but it pinches out a few hundred yards to the north. It is a dark-gray limestone pebble conglomerate with a dark reddish-gray matrix.

Dockum Group

The Triassic Dockum Group consists of the lower Santa Rosa Sandstone and the upper Chinle Formation. The Santa Rosa Sandstone near the base of the Dockum Group is fine to medium grained, cemented with silica, and buff to white. It forms cliffs and is a good marker.

The Chinle Formation is generally poorly exposed, but along the eastern edge of the mountains it consists of a dark-purple shale which is slightly metamorphosed. In the extreme northeastern corner of the mountains, the rocks are red shale and siltstone. Elsewhere the Dockum Group has been metamorphosed to white, gray, and black hornfels, or to a specularite-rich epidote rock. Approximately 1000 feet of the Dockum Group crops out in the San Pedro Mountains, the upper part being covered by alluvium to the east of the mountains.

IGNEOUS ROCKS

General Statement

Monzonite and rhyolite porphyry are the principal igneous rock types in the San Pedro Mountains. The monzonite grades into monzonite porphyry and latite porphyry. Diabase porphyry dikes occur locally.

Thinsections were prepared from 20 of the numerous samples collected in the field and were studied primarily to classify the rock types.

The rocks were classified according to Wah1strom (1955, p. 307-320). A rock of monzonitic composition is called a monzonite porphyry when the groundmass is greater than about 10 percent, and a latite porphyry when the groundmass is more than 50 percent.

Diabase Porphyry

Several diabase porphyry dikes occur in the eastern part of the mountains. In hand specimens the porphyry is dark green with prominent black hornblende phenocrysts up to 1.5 cm long and 0.5 cm across. Diopside phenocrysts of the same size as the hornblende occur in two of the dikes. In some dikes the hornblende has been altered to chlorite, and one dike contains only diopside phenocrysts. In one place small feldspar phenocrysts 1 x 3 mm occur. In most places, the groundmass is altered to a pale cream color.

In thinsections the diabase porphyry consists of about 30 percent hornblende phenocrysts and about 60 percent of fine-grained plagioclase microlites, of approximate composition An_{57}. Most of the remaining 10 percent is chlorite, with traces of magnetite and apatite.

Monzonite

The four stocks in the eastern part of the mountains and the small stock in Old Timer Gulch are monzonite. In hand specimens the monzonite is gray, uniformly medium grained. In the outcrop it weathers to slabby, slightly rounded boulders. It is resistant to weathering and the stocks form prominent peaks.

In thinsections the monzonite is composed of quartz, orthoclase, plagioclase, hornblende, chlorite apparently derived from hornblende, magnetite, apatite, sphene, and occasional sericite. The ratio of orthoclase to plagioclase ranges from about 1:1 to 1:4, and the amount of quartz is generally as much as 6 percent or 10 percent. The composition of the plagioclase ranges from An_{38} to An_{45}, and the centers of zoned plagioclase crystals are as calcic as An_{55}.

Monzonite Porphyry and Latite Porphyry

Monzonite porphyry and latite porphyry form dikes, sills, and laccoliths. In addition, the porphyries commonly form shells around the monzonite stocks.

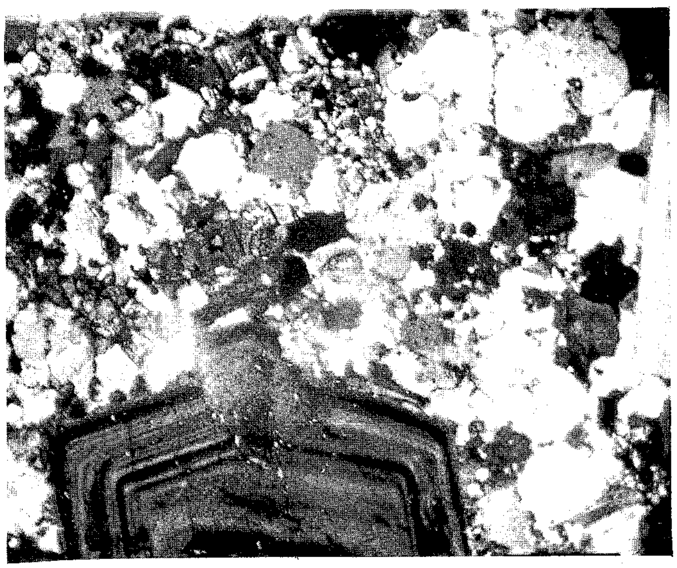
At the edges of some stocks a complete gradation was observed from monzonite to monzonite porphyry to latite porphyry. Four samples for thinsections were collected from a line 40 feet long, in which monzonite with no groundmass at all graded into a latite porphyry with 53 percent groundmass (pl. 2). The size of the particles in the groundmass varies from about 0.2 mm where the groundmass first appears to less than 0.01 mm,

The appearance and mineralogy of the two porphyries is essentially the same, except for the amount of groundmass. In hand specimens the porphyries are bluish gray with white rounded to angular feldspar phenocrysts 1 to 5 mm in diameter. In outcrops the porphyries weather to spheroidal boulders. In most places the porphyries are not very resistant to weathering, and in many places dikes and sills must be traced by float at the surface.

In thinsections the porphyries are composed of the same minerals as the monzonite described above. In some places the plagioclase phenocrysts have been altered to epidote. In the coarser groundmass of some monzonite porphyries, the principal mineral is orthoclase, with some quartz and plagioclase. In the porphyry with fine-grained groundmass, plagioclase predominates in the phenocrysts, and it is believed that orthoclase is the main constituent of the groundmass. The composition of the plagioclase phenocrysts varies from An_{35} in some specimens to An_{45} in others. The amount of quartz in the porphyries ranges from none at all to as much as 9 percent, the average being about 3 percent in the sections examined.

Smith et al. (p. 8-9) described the rock as syenite, while Yung and McCaffery (1903, p. 351) classified it as a syenite porphyry. Lindgren (Lindgren and Graton, 1906, p. 171) called it a granodiorite porphyry and stated that his specimens showed crystals of ande sine 2 to 3 mm in diameter and black prisms of horn-

A. Monzonite. Collected at 0 feet.



B. Monzonite porphyry with 3-5% groundmass.
Note zoned plagioclase. Collected at 17 feet.

Photomicrographs of samples grading from monzonite to latite porphyry. Samples were collected in a 35-foot line at the edge of the stock northeast of Oro Quay Peak.

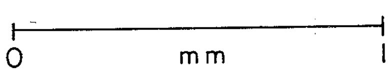


Plate 2.

C. Monzonite porphyry with 37% groundmass.
Collected at 26 feet.

D. Latite porphyry with 53% groundmass. Compare
fineness of groundmass with B. Collected at 35 feet.

Photomicrographs of samples grading from monzonite to latite porphyry. Samples were collected in a 35-foot line at the edge of the stock northeast of Oro Quay Peak.

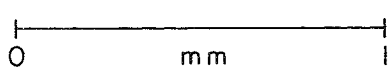


Plate 2.

blende set in a microcrystalline groundmass composed of quartz and orthoclase. He also gave the following partial analysis:

SiO_2	62.08 percent
CaO	4.62 percent
Na_2	4.76 percent
K_20	2. 84 percent

Rhyolite Porphyry

Rhyolite porphyry sills are common in most parts of the mountains, whereas rhyolite porphyry dikes are rather few in number and are confined to the eastern part of the range. Rhyolite porphyry partly encircles several of the monzonite stocks and appears to have risen from the same source.

In hand specimens, the rhyolite porphyry is white to light yellow and very fine grained with sparse to moderately abundant phenocrysts of orthoclase and quartz. In one sill small euhedral orthoclase crystals may be broken out of the rock. At some places the quartz phenocrysts are subhedral corroded hexagonal dipyramids, representing former high-temperatures. In outcrops the porphyry weathers to angular fragments.

In thinsections the rhyolite porphyry is composed of quartz, orthoclase, and plagioclase, with traces of biotite, magnetite, sericite, apatite, sphene, and hornblende. The amount of quartz ranges from 6 to 11 percent, the amount of orthoclase in phenocrysts from 16 to 25 percent, and the amount of plagioclase from traces to 15 percent. The thinsection of the most representative sample showed only traces of plagioclase. The groundmass is probably composed primarily of orthoclase and quartz.

Augite-bearing Monzonite Porphyry

A monzonite porphyry which occurs as a small pipe and a dike in San Lazarus Gulch is so different from the other monzonite porphyries in appearance, texture, and mineralogy that it is considered separately.

In hand specimens the porphyry is white with conspicuous glassy orthoclase phenocrysts averaging 2 cm in length and 1 cm in width, with abundant euhedral hornblende prisms 2 mm wide and 5 mm long. The porphyry weathers to slightly rounded slabby boulders.

In thinsection the porphyry is composed of 15 percent orthoclase, 40 percent plagioclase, and no quartz. The composition of the plagioclase is An_{33}, more sodic than in any other igneous rock in the San Pedro Mountains. In addition to 5 percent hornblende, 5 percent augite was noted. Sphene, apatite, and magnetite occur in minor amounts.

Age Relations of Igneous Rocks

Relative ages of different igneous rocks were determined in the field from crosscutting and gradational relationships.

The first intrusions in the San Pedro area were diabase porphyry dikes. Next, early monzonite stocks were intruded and closely followed by rhyolite porphyry; then later monzonite stocks were emplaced. The later stocks gave rise to most of the monzonite porphyry and latite porphyry dikes and sills. It is not clear when the augite-bearing monzonite porphyry was intruded, since it is not in contact with other igneous rocks. But in Los Cerrillos (Disbrow, 1953, p. 15) and in the Ortiz Mountains (Peterson, 1958, p. 49-50) a similar augite-bearing monzonite porphyry represented the last surge of intrusions.

METAMORPHIC ROCKS

Sedimentary rocks in the San Pedro Mountains have been extensively metamorphosed by heat and fluids emanating from the intrusions. The intensity of metamorphism usually diminishes with distance from the intrusion but it is also controlled by structural factors (pl. 3).

Metamorphic rocks were examined cursorily during the course of field work. Minerals which could not be identified in the field were determined by oil-immersion methods under the microscope.

Marmorized Madera Limestone occurs on the east side of Old Timer Gulch adjacent to a monzonite porphyry dike and in the uppermost beds of the limestone at the San Pedro mine, associated with tactite. At the San Pedro mine marble is separated from the nearest monzonite dike by tactite, and the sugary marble grades into fine-grained limestone away from the tactite. Where the limestone contained argillaceous layers, these are now resistant hornfels that may stand out in relief on weathered surfaces.

The monzonite stock which forms Oro Quay Peak has metamorphosed the limestone of the San Andres Formation adjacent to the stock to a coarsely crystalline marble which grades into finer-grained marble and finally into limestone. The coarse marble is exposed at the Silica mine but is covered elsewhere. At one point about 1000 feet from the stock, abundant tremolite needles were noted in very fine-grained, gray dolomitic marble.

Tactite has resulted from the complete replacement of parts of the Madera Limestone around the stock in Old Timer Gulch and in the uppermost beds in the limestone exposed on the west side of San Pedro Mountain. The beds are above the exposed monzonite porphyry laccolith. Replacement has taken place adjacent to a monzonite porphyry dike but not at the roof of the laccolith. The replaced beds also dip toward a porphyritic monzonite pipe in San Lazarus Gulch and toward the Oro Quay stock (pl. 4, A-A'). Replacement has probably resulted from fluids emanating from the dike, pipe, or stock but not from the laccolith.

The tactite is composed primarily of garnet, with minor amounts of tremolite, epidote, orthoclase, chlorite, and quartz. The orthoclase is present in one place as a massive constituent of the tactite and is different in appearance from the adularia present in vugs. Minor amounts of specularite, magnetite, pyrite, and chalcopyrite are also present locally. The garnet in the upper part of the Madera Limestone is all birefringent, and its determination presents a special problem. The following table summarizes the properties:

Color	2V	Sign	Minimum index	Maximum index
brown		+	1.81	1.87+
green	750	+	1.81	1.81
brown	60°	-	1.77	1.825
brown	large	+	1.81	1.88

The indexes measured do not represent <u>nx</u> and <u>nz</u> for a single composition.

The garnets are usually zoned, with areas of various birefringences and, therefore, different <u>x</u> and <u>z</u> indexes. Few of the samples examined contained isotropic zones.

Since the indexes nx and nz cover a rather wide range, ny was taken as the possible index of isotropic garnet of the same composition. Although the indexes of the garnets are nearest that of almandite, $3FeO \cdot Al_2O_3 \cdot 3SiO_2$ (n=1.830), their color suggests grossularite, $3CaO \cdot Al_2O_3 \cdot 3SiO_2$ (n=1.735), or andradite, $3CaO \cdot Fe_2O_3 \cdot 3SiO_2$ (n=1.895). If the garnet were almandite, all the calcium from the limestone would have been removed. On the other hand, garnet with a composition between grossularite and almandite would require the addition of only iron and silica, the aluminum being present in the argillaceous parts of the limestone. Although the garnet of marble and tactite aurioles is known to be dominantly grossularite with minor proportions of almandite and andradite, the positive confirmation requires either density or unit-cell data to supplement the optical data. Nonetheless, the garnet is tentatively assigned to a grossularite-almandite composition.

Hornfels occurs throughout the San Pedro Mountains in the shaly beds of the Madera Limestone, the Abo Formation, and the Dockum Group. It ranges in color from white to black and various shades of green and brown. In many places it is flinty and extremely hard, while adjacent to the large stocks it is soft and clay-like. Where redbeds have been metamorphosed, the iron has been incorporated in finely disseminated green minerals such as epidote and chlorite. Garnet nodules are abundant locally. Red-brown garnet from one unaltered nodule was biaxial negative, with minimum index 1.82 and maximum index 1.86. The garnet is probably nearest to almandite. Hornfels is the principal host rock for gold veins possibly because of the ease with which it fractures.

Any quartzite produced by contact metamorphism is not easily distinguished from that produced by diagenetic sedimentary processes. No contact metamorphic minerals were noted in quartzite in the San Pedro Mountains,

STRUCTURE

Regional Setting

The San Pedro Mountains lie in the San Pedro—Ortiz porphyry belt, a north-trending alignment of five intrusive centers about 25 miles long and 5 miles wide. From north to south they are the Cienega center, Los Cerrillos, Ortiz Mountains, San Pedro Mountains, and South Mountain (p1, 5).

The porphyry belt lies to the east of the Rio Grande depression and forms an echelon with two north-trending mountain ranges, the Sandia to the southwest and the Sangre de Cristo to the northeast. The Estancia basin lies southeast of the belt.

Sedimentary rocks in the porphyry belt generally dip to the east and northeast, in conformance with the general dip of the rocks in the Rio Grande trough west of the belt to the Santa Fe embayment east of the belt. Since this general easterly dip may be observed outside the areas affected by the intrusions, tilting has probably resulted from faulting associated with the development of the Rio Grande trough.

In general, the intrusive centers fall on a nearly straight line. In detail the arrangement is more complicated. The two principal intrusive centers in the San Pedro Mountains do not lie on the straight line but are equidistant to either side. A line of five centers of laccoliths in the Ortiz Mountains trends north-northwest from the belt, and a small plug at the La Bajada mine is several miles west of the belt.

The reason for the northerly straight trend of the porphyry belt is obscure. No folds or faults exposed at the surface connect the line of intrusives. The trend may be controlled by a fracture or belt of fractures in the Precambrian basement. A few of the intrusive centers show some relationship to exposed faults, although these faults show no apparent relationship to the porphyry belt as a whole. The five laccolith centers in the Ortiz Mountains, mentioned above, lie directly in line with the La Bajada fault. Intrusives in the San Pedro Mountains are cut by faults related to the northeasterly-trending Tijeras fault system. The San Pedro Mountains lie in a horst between the Dooley fault on the southeast and the Golden fault to the northwest. The largest stock in the San Pedro Mountains, at Oro Quay Peak, is cut by the Dooley fault. Several faults appear in the center of the horst and bifurcate to the north. The stock in Old Timer Gulch is elongated parallel to a branch of one of these faults and lies adjacent to it.

Dr. V. C. Kelley (oral communication, 1960) has suggested that South Mountain is offset from the line of the porphyry belt by strike-slip movement in the Tijeras fault system. If a line is drawn through the Cienega intrusive center, Cerro Bonanza in the Cerrillos, the eastern part of the Ortiz intrusives, and the Oro Quay stock in the an Pedro Mountains, South Mountain does indeed appear to be offset a few miles to the southwest along the Dooley fault (p1. 5). But this line misses Grand Central Mountain in the Cerrillos, the largest intrusive center in the porphyry belt. If the line is drawn through the center of Grand Central Mountain. the central stock of the Ortiz Mountains, and the center of the San Pedro Mountains, then the center of South Mountain falls directly on the line. The author feels that straightness or offsets in lines between intrusive centers is of little significance, since the pattern of intrusions in the porphyry belt is rather irregular.

The San Pedro Mountains appear to be more closely related to South Mountain than to the Ortiz intrusives. A rhyolite sill was traced from near San Pedro village to the west slopes of South Mountain, and the source of a laccolith which pinches, out on the west slope of South Mountain appears to have been the San Pedro Mountains. To the north the San Pedro Mountains are separated from the Ortiz Mountains by a fault or series of faults with a total vertical displacement of more than 5000 feet along the East fault (Emerick, p. 54-55).

Igneous Forms

Stocks and Pipes

Five monzonite stocks and one augite-bearing monzonite porphyry pipe have intruded the San Pedro Mountains. The stocks vary from about 1000 to 2000 feet in diameter and the pipe is about 100 feet in diameter. The stocks are roughly circular to elliptical, in plan and the pipe is circular.

Several faults intersect at the Old Timer stock, and one dike which was fed by the stock followed a fault until the dike pinched out. The pipe, which is called Castle Rock, has intruded near the intersection of several major faults. The two largest stocks have intruded within a few hundred feet of each other, and a line connecting the centers of the two trends north-northeast. The larger of the two stocks, which forms Oro Quay Peak, and the two remaining stocks lie in a straight line trending east-northeast. The stocks decrease in size along the line toward the east, with the largest on the west, the middle-sized stock in the middle, and the smallest at the east end.

Laccoliths

The mountains of the San Pedro—Ortiz porphyry belt have been termed "laccolithic mountains" since the earliest geologists examined them.

In 1898, Herrick (pc, 113) called San Lazarus Gulch "essentially an old andesite crater with more or fewer parasitic acid flows."

Perhaps Yung and McCaffery (p. 353) believed that Oro Quay Peak was the eroded conduit of the laccolith. But it appears that they did not recognize the laccolith exposed on San Pedro Mountain when they described it: "The intruded monzonite porphyry has entered like a wedge under the western end of the mountain, tilting the strata about 13 degrees to the east." They say nothing about this being a laccolith.

Lindgren is probably the first to have recognized the laccolith (Lindgren et al., 1910, p. 170).

Keyes (1909, p. 368) visited the San Pedro Mountains in 1909, several years after Lindgren, but Lindgren's observations had not yet been published. Keyes interpreted the structure of the San Pedro Mountains as in Figure 1.

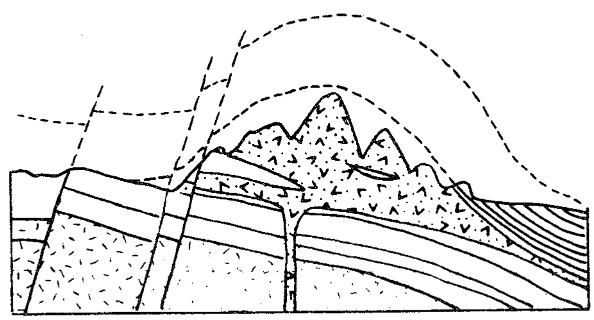


Figure 1. Structure of the San Pedro Mountains (Keyes)

When mapping was begun in June 1959, the author was skeptical of the many prospectors' reports of a laccolith, but mapping has conclusively proved the laccolithic nature of these intrusions. In most places the roof is concordant and dips away from the center of the laccolith (pl. 4). The base of the laccolith usually follows the bedding, but it could not be seen everywhere because at places the edges of the laccolith are cut by low-angle normal faults.

The small monzonite porphyry stock in Old Timer Gulch is interpreted as the feeder for the laccolith. On the north side of the stock, a dike grades from coarse, dark monzonite to light latite porphyry. On the opposite side of the stock, the monzonite grades into monzonite porphyry and latite porphyry in a small sill.

A long patch of monzonite porphyry crops out along the western margin of the mountains. The top of this intrusive is concordant; its bottom is not exposed. In preparing a north-south cross section through San Pedro Mountain (p1. 4, B-B'), it was noted that the beds are bent downward at the south edge of the mountains beneath the exposed laccolith. This bend in the beds and the concordant porphyry beneath the exposed laccolith were interpreted as belonging to another, largely buried, laccolith. This is shown on sections A-A' and B-B' (pl. 4).

Sills

Rhyolite porphyry and latite porphyry sills are common in the San Pedro Mountains, They range in thickness from a few feet to more than 400 feet. The sills are usually extensive and were not observed to pinch out along the strike in this small area (pl. 6).

The rhyolite sills seem to be somewhat more irregular than the latite porphyry sills. In many places the rhyolite sills follow the bedding to some joint or fault, cross the bedding for a short distance, then follow the bedding again. A sill of this type is illustrated in Plate 4, section B–B'.

Dikes

Dikes intrude all the sedimentary formations in the area. Rhyolite porphyry and latite porphyry are the principal rock types, but a few diabase dikes occur.

Most of the dikes follow nearly vertical fractures and are straight lines on the map, but some dip at angles as low as 50 degrees and describe a rather irregular outcrop over rugged terrain. Other dikes appear to be vertical but are rather irregular and branching. These are near the stocks in an apparently highly faulted area (pl. 7).

The augite-bearing monzonite porphyry dike presents a problem. Jointing in the dike varies from almost horizontal to 10 degrees west. The sedimentary rocks nearby dip 21 degrees east. At the top of the ridge above Castle Rock, the same porphyry is very thin, rests on the sedimentary rocks, and may be lifted off in slabs a few inches thick. The joints and the attitude of the slabs lying on the sedimentary rocks indicate that the dike is probably a rather thin erosional remnant, but this is not certain.

In most parts of the mountains the dikes are randomly oriented, but on the small hill in the northeastern corner of the area, dikes radiate from either the small monzonite stock or from a point at the edge of the middle monzonite stock mentioned above (pl. 7) The radiating dikes are rhyolite porphyry and latite porphyry. They are probably more numerous on this hill because the intruded rock is Chinle shale, the rather incompetent upper part of the Dockum Group.

Irregular, dikelike intrusions of rhyolite porphyry follow the margins of the stocks in many places (pl. 7) It appears that this was the source of the numerous rhyolite porphyry sills and dikes.

Faults

The San Pedro Mountains have been faulted extensively. It was mentioned before that the San Pedro Mountains are part of the San Pedro horst, which is a wedge-shaped block between two faults of the Tijeras fault system (pl. 5) The Dooley fault on the south side of the horst cuts through Oro Quay Peak and is lost in the Recent sediments on the north side of the mountains. The Golden fault passes somewhat to the northeast of the San Pedro Mountains.

A pair of faults appears in the center of the San Pedro horst and curves to the northeast, finally joining the Golden fault. The eastern fault bifurcates about one-half mile north of San Pedro village and passes through Old Timer Gulch. The Old Timer stock lies a few hundred feet west of this fault.

Many of the larger faults are parallel to the Dooley fault or to bifurcations of the larger faults east of the mountains, but many other faults are at right angles to the Tijeras fault system (pl. 8)

The faults are all normal faults and are believed to dip from 70 to 90 degrees. The attitude of the dipping faults was determined from the amount of deviation from a straight line on a map as the fault passes over a high point in the mountains.

Although a fault in San Pedro Mountain was found to have a dip of about 70 degrees north by the method outlined above, its apparent dip on section A-A' is about 20 degrees east, because it is nearly parallel to the line of the section.

Displacement on the faults is as much as 300 feet. The largest displacement could be measured from the relative displacement of the San Andres Formation. Many sills served as marker horizons from which dip separations could be measured. Two ages of faulting are readily apparent in the area. Faulting prior to the intrusions provided channelways for emplacement of dikes, and intersections of several faults apparently served as loci for the emplacement of the stocks. Faulting subsequent to intrusion has probably taken place largely along older faults, and the intrusive bodies have been faulted.

Folds

The general dip of the sedimentary rocks is from 10 to 50 degrees easterly. Folding has occurred on a minor scale associated with intrusion.

General doming is apparent around several stocks and over the laccoliths. Doming perhaps is best developed around the stock in Old Timer Gulch beneath the upper laccolith. Here the beds dip away from the stock on all sides. In a general way, beds are domed above the lower laccolith, and the beds above the upper laccolith dip rather uniformly to the east but are turned downward somewhat sharply at the edges of the laccolith.

Beds are turned upward at steep angles around the principal stocks, especially at Oro Quay Peak. Just east of this peak the beds dip outward from it.

General doming is especially apparent around the larger of the stocks northeast of Oro Quay Peak, due to the directions of the dips and the radial dikes and faults.

Doming caused by intrusions combined with the easterly dip of the area has given the San Pedro Mountains a general anticlinal structure.

Summary

Two periods of deformation are responsible for the major structures in the San Pedro Mountains. Faulting and folding is associated with a period of intrusion, while later deformation consists principally of faulting.

Three stocks at the eastern end of the mountains lie on a northeast-trending line. Although no single fracture connects all three stocks, intrusion probably has taken place through a fracture in the Precambrian basement, possibly caused by intrusion of the Oro Quay stock, the earliest and largest of the three.

Doming and the general anticlinal structure of the mountains has been caused by intrusion of laccoliths and stocks.

Post-intrusion faulting may be related to the uplift of the San Pedro horst along the Dooley and Golden faults in the Tijeras fault system. The Dooley fault is joined by a closely related fault just north of the Oro Quay stock. The two largest north-trending faults which pass through Old Timer Gulch are related to the bifurcating faults to the west of the mountains, at the center of the Tijeras fault system.

Other post-intrusive faults are arranged in a rather random manner and are difficult to interpret.

GEOLOGIC HISTORY

The geologic history of the San Pedro Mountains may be determined best by study of adjacent areas. In the San Pedro Mountains faulting has obscured the thicknesses of the formations; intrusion and metamorphism have largely destroyed the original lithology; and deposition of gravels surrounding the mountains has covered the strata above and below the exposed section.

The Precambrian basement in the area consists of a complex series of metamorphic rocks intruded by granite. During the late Pennsylvanian period a thick sequence of limestone and shale was laid on the eroded Precambrian rocks. After a period of nondeposition or slight erosion at the end of the Pennsylvanian, continental Permian rocks were deposited. During San Andres time the sea returned and laid down sandstone and limestone. Nondeposition and perhaps slight stripping intervened until late Triassic when sandstone and shale were deposited under continental conditions.

Sedimentation appears to have ceased during early Jurassic time prior to the deposition of the Entrada Sandstone. Beds of Todilto limestone and gypsum above the sandstone indicate the invasion of a lake or a shallow arm of the sea over most of northern New Mexico. Thick sandstone and variegated shale were deposited under continental conditions later during the Jurassic.

Some broad stripping may have taken place through early Cretaceous, before the seas .invaded the Rocky Mountain geosyncline in late Cretaceous time. During the persistent subsidence of this geosyncline a thick sequence of marine shale and sandstone was laid down.

Broad upwarping took place at the end of the Cretaceous, and the Rocky Mountain area underwent considerable orogeny. During the Eocene the Galisteo Formation was deposited unconformably on Upper Cretaceous rocks by rivers flowing into and through a broad basin in the area of the porphyry belt, which was deepened and enlarged by warping contemporary with deposition (Stearns, 1953, p. 467).

The earliest period of "modern" deformation in the San Pedro Mountains occurred at the time of the first intrusions. It is probable that this was contemporaneous with intrusions in the other centers of the porphyry belt. Intrusion in the Cerrillos and possibly the Ortiz Mountains was followed by eruption. Disbrow (p. 19-22) believed that the Espinaso Volcanic Formation was de-rived from the Cerrillos eruptive center. In a later paper (Disbrow and Stoll, 1957, p. 11), Disbrow presented evidence for dating the base of the Espinaso Formation as early Oligocene. He further states that the extrusion of the formation may span Oligocene and early Miocene time. The date of the San Pedro intrusions may, therefore, lie between early Oligocene and early Miocene.

Later deformation in the San Pedro Mountains probably occurred during the same period as the major deformation of the Sandia uplift. Reynolds (p. 53) stated that deformation in the Hagan—La Madera area of the Sandia Mountains definitely began after deposition of the Espinaso Volcanics, and that two phases of deformation took place prior to and after deposition of the late Miocene and Pliocene Santa Fe Formation, while some continuing deformation may have occurred during the deposition of the Santa Fe Formation.

Uplift of the San Pedro Mountains probably took place from late Miocene through Pliocene. Stearns (p. 473) stated that the Santa Fe Formation contains fragments of contact metamorphic rocks which can only have been derived from the Ortiz Mountains, San Pedro Mountains, and South Mountain.

Since the uplift of the porphyry belt, continual erosion has taken place in the mountains, forming thick deposits of gravel at their bases. The gravel deposits themselves have been subjected to erosion in Quaternary time.

Economic geology

INTRODUCTION

The New Placers mining district has a long history of production of base and precious metals. Gold placers encircle the San Pedro Mountains, This gold was derived from veins and bedded deposits. Gold, lead, zinc, iron for fluxing, and some copper have been produced from the veins. Copper and gold have been produced from contact metamorphic bedded deposits. Limestone has been quarried from the Madera Limestone, Recently, pure quartz sand has been mined from the Glorieta Sandstone, and development work has prepared the sandstone for open-pit mining. Other resources have been explored but not yet developed. Magnetite occurs in contact deposits, and tungsten reserves have been investigated by the U.S. Geological Survey (Smith et al.).

HISTORY AND PRODUCTION

The porphyry belt has a long and colorful history of mining dating back to prehistoric times, The Indians of New Mexico mined turquoise in the Cerrillos area for many years before the Spaniards came to New Mexico, The Spaniards were especially eager to find mineral deposits. Northrop (1959, p, 10) states that mineral deposits were discovered near Cerrillos as early as 1581, and that assays of ore from the Cerrillos—Ortiz region were made in 1583. Northrop (p. 14) also cites a reference which claimed that the Ortiz mine was a famous gold producer in 1680, Jones (1904, p. 30) tells that the Mina del Tiro was operated before 1680, and Northrop (p, 17) says that a lead mine in the Cerrillos was granted by Governor Hurtado in 1717 and that "gold was mined at La Mina de la Tierra (or del Tiro) in the Cerrillos district in 1722." None of the New Mexico historians refers to mining in the San Pedro Mountains prior to 1839, but Fray Dominguez mentions in his report (The Missions of New Mexico, 1776) that the place name San Pedro, among others, was found in the baptismal book of San Juan, In addition, he prepared an excellent map which shows a village named San Pedro at the western foot of the present San Pedro Mountains. It is probable that San Pedro was even then a mining village. It is not an especially favorable area for farming, Wells had to be dug for water, and it was many miles to the nearest protection from Indian raids.

In 1828, gold was discovered in the Ortiz Mountains by a herder. Although many later writers simply state that it was a sheepherder, Prince (1883, p. 241) states that it was discovered by a citizen of Sonora who was herding cattle. The herder saw some rock which resembled gold-bearing rock in his native state, and when he examined the rock he found that it did contain gold. This discovery led to the exploitation of the placer deposits at the foot of the Ortiz Mountains.

Lode gold was discovered in the Ortiz Mountains in 1833 by a man named Ortiz. Legend has it that Ortiz knew nothing about mining and went into partnership with an experienced Spaniard named Lopez. In order to get rid of Lopez, the greedy Ortiz persuaded officials to deport Lopez by an old edict which said that foreigners could not work in the mines. But Ortiz and the corrupt officials did not obtain “one grain of gold” (Jones, p. 23).

In 1839, the New Placers were discovered, and the village of Tuerto, now Golden, rose into prominence as a business center. By 1845, the town had 22 stores and transacted more business than Santa Fe (Prince, p. 243); by 1849, it had a population of 7000 with 35 stores and numerous saloons and gambling halls. Jones (p. 25) stated that San Lazarus Gulch was a "steady producer at this time." During this period the annual output of the Old Placers and New Placers reached $250,000 and as many as 2000 men congregated there to work during the winter (Prince, p. 243).

Water was so scarce that winter was the "favorite time for working the placers. Snow was melted in little reservoirs in the arroyos with hot rocks, and the gold was then washed with wooden bateas, or hand-made gold pans (Jones, p. 21).

Prince first stated that the annual production of the two placer districts reached $25,000 per year in 1845, and Jones cited Prince as stating that the annual production of gold taken out of the Old Placers was $60,000 to $80,000 between 1832 and 1835; Wells and Wooton (1932, p. 18) report that in later years (after 1835) the production of the Old Placers was not more than $30,000 to $40,000 per year. If Prince's original figure is correct, the New Placers district produced $210,000 in 1845. This is rather remarkable, considering that under the Mexican laws, each miner held only one claim, ten paces in all directions from his discovery pit. If 2000 miners were there, this would be an average of $100 per miner for a winter's work. During the depression from 1932 to 1935, poverty-stricken miners earned from $3 to $10 per week in the New Placers (James, 1955, p. 21), and present-day prospectors report that they recover from $2 to $4 in gold per day.

Several early travelers mention the San Pedro mine. Dr. Wislizenus (Bullock, 1952, p. 5) visited the San Pedro mine in 1846; it was not being worked at the time. He reported that a Mr. Tournier had already sunk a shaft 40 varas (about 110 feet) and drifted 30 varas (about 80 feet). The ore was carried by mules to the town of San Pedro and treated in an amalgamation mill. Mr. Tournier told Dr. Wislizenus that he worked about 2-1/2 cargas (750 pounds) of ore each day with mule-driven mills, and he obtained about $l2 worth of gold per day.

In the same year Lieutenant J. W. Abert visited San Pedro. He found the life of the placer miners very miserable and said he was happy he did not own a gold mine. He also visited the San Pedro mine and collected specimens of ore (Bullock, p. 5).

Perhaps the most accurate early history of the San Pedro mine was related by M. A. Otero, former governor of New Mexico, in his book My Life on the Frontier. The mine was rediscovered about 1840 by Antonio Aguilar and Mariano Varela, both from Chihuahua. They were financed by a Chihuahua lawyer, Don Carlos Jaquez. The ore was carried to Chihuahua on the backs of burros. Later, Aguilar and Varela gave the deed to the mine to Otero's uncle for payment of debts.

Just before the Mexican War, Jose Serafin Ramirez secured a small land grant from the Mexican government. After the U.S. occupation, the land grant was recognized and a patent was granted in 1875. The grant, called Canon del Agua, had no connection with the mine and had been obtained for the purpose of establishing a sheep headquarters.

News of the Civil War depopulated the area overnight, and Golden was deserted. Mining activity ceased completely, and it was many years before activity resumed (Bullock, p. 6).

Otero tells us that sometime about 1880, the Santa Fe Ring, an unscrupulous and powerful gang, found out about the San Pedro mine and arranged for Ramirez to have his grant resurveyed. The boundaries were exchanged, and the east boundary of the grant was now the west boundary, so the: grant included the San Pedro mine property. Immediately the San Pedro and Canon del Agua Mining Company was organized in Boston, where shares moved like wild-fire.

At this time Otero's uncle died and Otero's cousin discovered the deed to the mine in his father's papers. Otero's father immediately took up the matter and consulted Carlos Jaquez, now a judge in Chihuahua, whom he found still had an interest in the mine. Judge Jaquez and the older Otero were able to identify the property easily and started legal proceedings to secure the mine. When the Santa Fe Ring heard the news, the mining company set up fortifications at the mine. They built stone breastworks, an armory, and even installed a small French cannon. Notices were posted at the mine and in the village and on numerous trees in the vicinity.

Otero's father had trouble prosecuting the case because the Federal Judge, L. B. Prince, was too soft and would not oppose the Santa Fe Ring. Otero's father pressed for Prince's dismissal or resignation and he finally resigned. Unfortunately, the Santa Fe Ring then secured the appointment of one of their own members.

At this tithe Otero's father died and all proceedings were stopped. The Santa Fe Ring felt secure, but they had not reckoned with Otero himself.

Otero discussed the situation with several of his prominent friends; they decided that since they would be unable to obtain an injunction from the corrupt judge, they would be successful only by taking the mine by force of arms. He bought 65 new Winchester rifles and shipped them to a friend in Golden. Otero and a dozen men took a roundabout way to the mine and climbed down the shaft on a rope. Each man had a rifle on his back, a Colt pistol in his belt, and a flask of whiskey "in case of snakebite."

While they hid in the mine they counted 162 men who entered to go to work. They waited until the same number left for lunch and then rushed out the tunnel behind the miners, captured the mine, and forced the miners to go back down to the village without lunch.

Dynamite charges were set in the tunnels. Otero threatened to blast the mine if the company attempted to recapture the fortifications.

Unhappily, Otero was called back to Las Vegas on business, where he was arrested and brought to trial. Although Federal Judge Samuel B. Axtell, the Ring's appointee, presided, the jury returned a verdict of not guilty.

Because Judge Axtell was having trouble with the authorities in connection with his corrupt legal practices, he was forced to give Otero's men permission to surrender the mine to the court, and to appoint a custodian.

Several years later the case was decided in Otero's favor by another judge, and the verdict was upheld by the Supreme Court. The boundaries of the Canon del Agua Grant were declared fraudulent and the grant was resurveyed and its size reduced greatly. The land was then thrown open for mine location, but Otero's friends in Golden double-crossed him and claimed the San Pedro mine for themselves.

Bullock (p. 6) filled in the remaining details of the history of the San Pedro area. Before Otero interfered, the San Pedro and Canon del Agua company had begun extensive development work. Dams were built in Los Tuertos and Madera Canyons in the Sandia Mountains, and 22 miles of 14-inch pipe were laid to bring water for placer mining. Stamp mills and a 60-ton smelter were built. General U. S. Grant was elected president of the company, but when he heard that the stock jumped because his name was used, he resigned. Perhaps he had heard of the company's crooked dealings.

Bullock (p_a 6) mentioned the suit Otero's father initiated in 1881, and told that litigation shut down the San Pedro mine and that a drouth shut down the placer operations.

In 1887, a new gold strike was reported at San Pedro, and the Golden Hydraulic Company repaired the stamp mills, smelter, pipe lines, and reservoirs. Placer mining and work at San Pedro mine resulted in 250 employees on the regular payroll.

The Lewisohn family of New York acquired control of the San Pedro mine in 1889 and operated as the Santa Fe Gold and Copper Company. A 100-ton concentrator was installed in 1891.

The U.S. Supreme Court decision in 1892, upholding the Territorial Court ruling that the boundaries of the Canon del Agua Grant were fraudulent, opened up 3300 acres of mineral lands, which attracted numerous miners and prospectors.

During the 1890's an aerial tramway carried the ore from the San Pedro mine to the smelter at the village below. In 1900, a new smelter was built at the mine and operated until 1918 when it was destroyed in a fire (C. F. Williams, oral communication, 1960, and Ellis, 1929, p. 98).

In 1938, the Lewisohns sold the San Pedro mine to the Raskob Mining Interests, Inc. In 1940 and 1941, more than four million pounds of copper were mined, and then the mine was closed down. In 1945, the mine was sold to Mr. C. F. Williams, the present owner. Mr. Torn Scartaccini leased the mine in 1956 and has shipped a few carloads of ore since then.

Dr. V. C. Kelley of the University of New Mexico discovered scheelite in the mine in 1944, which led to an investigation of the tungsten reserves by the U. S. Geological Survey.

No records are available for the total production of the district. Northrop (p. 31) stated that 40 to 50 tons of ore valued at $250 per ton were produced in 1883. Lindgren et al, (p. 172) said that the production of copper from the San Pedro mine from 1889 to 1892 was several million pounds and that gold production for the district was $2000 to $4000 per year. Bullock (p. 9) stated that the San Pedro and Canon del Agua company produced about $60,000 worth of bullion per month before 1881. Smith et al, (table 1) cited Johnson's (1943) production figures for the San Pedro mine. From 1907 to 1918, about 8.5 million pounds of copper were produced; from 1923 to 1939, one million pounds were produced; and during 1940 and 1941, more than four million pounds were produced.

ORE DEPOSITS

Copper

The most important mineral deposits in the San Pedro Mountains are the copper deposits, which have been extensively exploited at the San Pedro mine. More than twelve million pounds of copper have been produced since 1907 (Smith et al., p. 3).

Bedded copper deposits occur on the western side of San Pedro Mountain and are limited to the upper beds of the Madera Limestone. The beds lie immediately below a rhyolite sill and as much as fifty feet above the monzonite porphyry laccolith. An easterly-trending monzonite porphyry dike forms a ridge on the western side of San Pedro Mountain. Some small copper deposits occur directly against the dike. The deposit at San Pedro mine is about 1000 feet from the dike. A monzonite dike was encountered in one drift in the mine, but it does not crop out at the surface and its attitude with respect to the ore bodies is not known.

The ore bodies are generally tabular or pod-shaped, parallel to the bedding planes. The ore bodies are highly irregular in outline but remain strictly confined to single favorable beds. The sizes of the ore bodies vary from patches of ore a few inches across to bodies 100 feet wide and 1000 feet long.

The upper limestone beds of the Madera Formation have been extensively replaced by massive garnet rock, or tactite. The limits of garnetization are sharply defined by a highly irregular "marble line." On the side of the "line" toward the ridge-forming monzonite porphyry dike, the limestone has been replaced by garnet, while on the other side the limestone has been metamorphosed to coarse, sugary marble. The marble becomes progressively finer grained farther away from the "marble line" and finally grades into unaltered limestone.

Smith et al. (p. 17-19) have discussed the relationship of the ore to the "marble line" in detail. They found that the ore occurs in the tactite adjacent to the "marble line," or not more than 200 feet from it in most instances. No ore occurs in the marble.

The volume of the original limestone was somewhat greater than that of the replacing garnet. This difference in volume is represented by abundant cavities, in which the ore has been deposited. The smaller cavities, up to several inches in diameter, were completely filled by ore and gangue, but larger cavities, some many feet in diameter, were not filled and permitted a second stage of deposition.

In the first stage of mineralization, chalcopyrite, bornite, pyrite, pyrrhotite, calcite, specular hematite, quartz, and chlorite were deposited in the openings iii the tactite. Scheelite is also reported to be disseminated in the tactite (Smith et al., p. 20). This ore is referred to as disseminated ore.

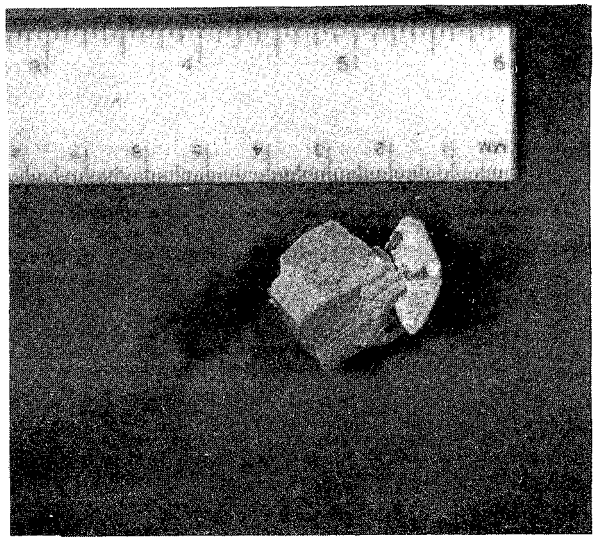
The second stage of mineralization is represented by coarsely crystallized filling of the larger cavities. Quartz, pyrite, chalcopyrite, and abundant calcite are common; lesser amounts of siderite are present in some places. Some scheelite crystals were observed in the coarsely crystallized material. In the weathered outcrop at the Spanish cut of the San Pedro mine, coarsely crystallized adularia is abundant.

Although the paragenesis of the ores has not been completely worked out, study of the coarsely crystallized material and a few polished sections of the disseminated ore has yielded some information on the sequence of deposition. Chalcopyrite has replaced both pyrite and pyrrhotite in disseminated ore. In the later stages of deposition, quartz crystals are enclosed by pyrite, chalcopyrite, and calcite. Pyrite crystals are enclosed by chalcopyrite, and some calcite encloses chalcopyrite. The calcite and chalcopyrite appear to have been deposited simultaneously, since small crystals of chalcopyrite are not attached to earlier minerals within the calcite. Striking pseudomorphs of pyrite after calcite give evidence of later replacement of calcite by pyrite (pl. 9).

Many of these minerals are exceptionally well crystallized in the San Pedro mine and deserve a brief description. Specular hematite is frequently found in cavities as rosettes of extremely thin crystals, which show a deep red internal reflection. Calcite occurring with hematite generally displays a rhombohedral form modified on the edges by scalenohedral faces. In one place these crystals were commonly twinned on the rhombohedron face (1011), Calcite deposited directly on the specularite often displays single scalenohedrons up to two inches long modified by the rhombohedron (4041). Calcite in the coarsely crystallized ore occurs as scalenohedrons usually about one inch long but occasionally up to six inches long. The scalenohedrons are often twinned on (0001) or (1011). A remarkable cyclic twin composed of six scalenohedrons twinned on (1011) and apparently on (1101) on a single central scalenohedron was discovered near the water level.

An unusual phenomenon observed in the San Pedro Mountains is the occurrence of quartz twinned according to the Japanese law, These twins are fairly common in many places in the San Pedro mine, and one other occurrence was noted on a dump in Old Timer Gulch,

Mineral collectors in Albuquerque have reported the occurrence of amethyst from a single vug in the Swan tunnel level of the San Pedro mine. A light-purple amethyst labeled San Pedro mine



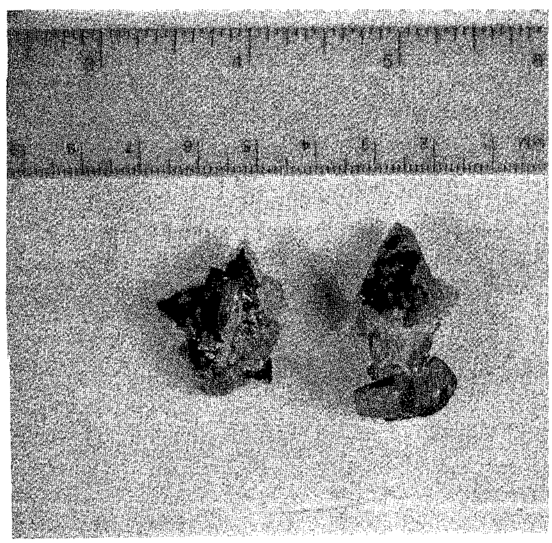


Plate 9. Pyrite pseudomorphs after calcite from the San Pedro mine.

in the museum of the Geology Department of the University of New Mexico is about two inches in diameter.

Chalcopyrite occurs in uncommonly large crystals, up to 3-1/2 inches across. Crystals whose principal form is the disphenoid (112) are commonly twinned on (112) and modified by a tetragonal scalenohedron, probably (531). Sherman P. Marsh has measured the interfacial angles on some highly modified crystals, 2 inches in length, which he found in a single vug at the water level. These crystals were associated with calcite, quartz, and scheelite. The measurements showed that the crystals included positive disphenoid (112), negative disphenoid (112), tetragonal prism of the first order (110), basal pinacoid (001) and the rare tetragonal scalenohedron (101) (fig. 2; p1. 10).

The large chalcopyrite crystals usually formed around a pyrite nucleus. These pyrite crystals, as a rule, are combinations of cube, octahedron, pyritohedron, and diploid, about half an inch in diameter. Simple octahedrons occur in the large cavities beneath the coarsely crystallized minerals. Pyrite cubes up to one inch across are not uncommon. The pseudomorphs of pyrite after calcite, mentioned above, are up to one inch long and faithfully follow the outlines of the calcite scalenohedrons. In all the cases observed, the pseudomorphs were connected to pyrite cubes from one-half to one inch across. Many of the calcite crystals were only partially replaced, and the point of attachment to the pyrite cube appears to have been the starting point of the replacement.

Euhedral scheelite crystals up to half an inch across were observed in the vuggy ore but are rare.

Siderite is found in several places in the San Pedro mine in two types of occurrences. In some of the smaller vugs it occurs as columnar aggregates of scalenohedral crystals growing vertically from the floor of the vug. In the upper part of the mine siderite occurs with calcite and limonite in partially oxidized ore as rhombohedrons half an inch across.

Adularia occurs as well-formed euhedral crystals up to 1-1/2 inches long in the Spanish cut at the San Pedro mine.

Tetrahedrite (Northrop, p. 358) and molybdenite (Smith et al., p. 16, and Northrop, p. 358) have been reported by earlier workers but were not observed by the present writer.

The copper deposits are oxidized to a depth of about 100 feet (Smith et al., p. 17). Chrysocolla, malachite, and azurite are rather common, and Smith et al. (p. 17) list melaconite (a powdery tenorite, CuO) and cuprite. A specimen in an old collection at the University of New Mexico, labeled San Pedro, Santa Fe Co., N. Mex., contained native copper in cuprite with quartz and malachite. The texture of the ore is typical of that from the San Pedro mine and the author has no doubt about the origin of the ore. This is the first record of native copper from this locality. Limonite

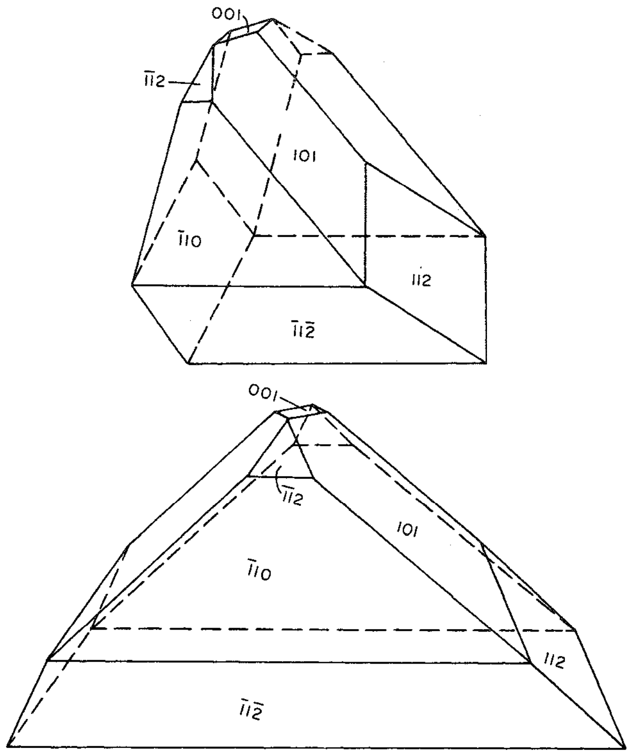


Figure 2. Chalcopyrite crystals from the San Pedro mine.

Plate 10. Unusually large chalcopyrite crystal from the San Pedro mine.

is abundant, and chalcanthite is found as a coating on the walls of the mines in many places. Melanterite was reported from diamond drill hole U-2 in the San Pedro mine (Smith et al., appendix p. 7). Smith et al. (p. 17) note that although chalcocite films coat chalcopyrite in several places, no noteworthy bodies of secondarily enriched ore have been found. This is probably due to the fact that the garnet rock is not sufficiently porous to allow free circulation of oxygen-charged ground water.

Minerals in the disseminated ore, especially specularite and pyrrhotite, indicate a rather high temperature of deposition. Later filling in the large open cavities apparently fits Lindgren's mesothermal deposits. This is indicated by abundant, coarse carbonates, especially siderite, and the lack of characteristic features of epithermal deposits, such as delicate crustified banding. The presence of the coarse adularia probably does not indicate low-temperature deposition. Adularia is usually regarded as a low-temperature mineral, but Lindgren (1928, p. 692-694) classifies certain veins in the Alps which contain coarsely crystallized adularia as mesothermal.

Smith et al. (p. 16) stated that the ore at the San Pedro mine averages about 3 percent copper, although locally much higher grade ore has been mined. Gold content has averaged about 0.05 ounce per ton and silver about 0.8 ounce per ton. High-grade pockets of gold have been encountered, and specimens of gold in calcite have been sold to mineral collectors.

In 1944, the underground workings of the San Pedro mine were examined by J. R. Cooper and F. W. Farwell, of the U.S. Geological Survey, following Dr. V. C. Kelley's discovery of scheelite. It was found that the areas of tungsten concentration do not always occur in areas of copper concentration. The highest grade of tungsten ore was estimated to be about 1 to 2 percent $W0_3$, whereas the average grade of mineable bodies was between 0.1 and 0.5 percent $W0_3$ (Smith et al., p. 20).

Gold

Veins and Bedded Deposits

Gold-bearing veins occur in all the metamorphosed areas and in all the igneous rocks in the San Pedro Mountains.

At both ends of the mountains the gold veins are clustered about the stocks. Veins are more numerous in the eastern end of the mountains where there are several stocks.

In the western part of the mountains the gold veins are most common in the latite porphyry and monzonite porphyry of the laccolith. In the central and eastern parts of the mountains the veins are most common in hornfels, although a few rich veins occur in monzonite. They do not occur in the tactite and unmetamorphosed rocks. Veins in rhyolite porphyry were apparently too poor to mine. In the laccolith and in Old Timer Gulch, the veins belong to two sets, one striking from N. 75° E. to N. 80° E., and the other striking from about N. to N. 25° E. In San Lazarus Gulch most of the veins strike from S. 60° E. to S. 50° E., and one vein strikes S. 30° E. In the vicinity of Oro Quay Peak, the veins belong to two intersecting sets, one striking from N. 10° E. to N. 30° E. and the other from N. 70° E. to N. 85°E. East of Oro Quay Peak, many of the veins are associated with dikes and these and other veins radiate from the largest of the eastern stocks.

Yung and McCaffery (p. 357) were the first to describe the character of the veins in the San Pedro Mountains, and subsequent reports have drawn mostly on their report. They describe the gold veins as being either crushed and fissured zones or banded fissure veins. Most of the veins in the district are of the first kind.

Yung and McCaffery (p. 357) further write that the veins have no definite walls. The gold and associated minerals have entered the cracks in the shattered rock and form a network of veinlets. There are a great number of these veins, but Yung and McCaffery say that they are "all small, isolated, pockety, and unreliable," and that there has been no successful mine on these veins. Most of the veins cannot be traced for more than a few hundred feet on the surface.

Banded fissure veins are quite rare. In the course of mapping, some pieces of banded float were picked up, but none was seen in any prospect. Yung and McCaffery (pa 361) gave the Ortiz mine in the Ortiz Mountains as the only good example of a deposit of this type.

Gold occurs in metasomatized beds in many places. Yung and McCaffery (p. 360) briefly mention this type of deposit. Lindgren et al. (p. 172) stated that the San Lazarus mines were on a bed which contained auriferous pyrite. Most of the bedded deposits observed were not more than 3 feet thick and 30 feet long on the outcrop.

Gold is associated with pyrite, calcite, quartz, and rarely barite. Yung and McCaffery (p. 358) stated that "the gold, which is usually coarse, occurs with these minerals, and occasionally furnishes fine specimens of wire and sheet gold." Ellis (p. 98) stated that in the Argo mine (Old Timer mine), "the ore occurs as free gold in fissure veins in porphyry, and the assay value is said to be from $10 to $100,000 per ton." Jones (p. 27) stated that “some very fine specimens of leaf and wire gold have been taken from the various properties. Beautiful specimens enclosed in calcite have been found in the Gold Standard mine.” In some places, the quartz contains free gold; at the Brooks mine and in the McKinley mine, free gold is associated with pyrite, quartz, and calcite (Lindgren et al., p. 172). Ellis believed that pyrite probably contained the gold. The quartz observed in these deposits ranges from massive white "bull" quartz to coarse crystals 1 mm long and 0.2 mm wide.

Some of the ores observed during the course of mapping were mostly pyrite, with little quartz and no calcite. One small fissure branching from a principal vein contained calcite, pyrite, and adularia crystals. The veins are all oxidized at the surface, but oxidation does not reach the water table in most places. In the oxidized portions of the veins the ore consists of quartz boxwork filled with limonite.

In bedded deposits, the gold occurs in pyrite in impure hornfels beds containing much garnet. In some places gold occurs in thin pyritized lenses in tactite.

Placer Deposits

Placer deposits were not examined in detail during the course of mapping. Yung and McCaffery (p. 361) described the placers in some detail, as follows: "Gold has collected in fan-shaped placers at the foot of each mountain arroyo. The gold is derived from the weathering of the numerous small veins and…all the gravel carries gold in small quantities." The gravel is coarsest at the edge of the mountains, where it contains boulders up to one foot in diameter, and is 20 to 30 feet deep on the bedrock. They state that "the richest streak is naturally next to the bedrock; and, judging from a great number of working-tests, this will run about $1 per cu. yd., while the surface will not average over 30 or 40 cents per cu. yd." Wells and Wooton (p. 20) stated that several unsuccessful attempts at dredging have been made and that the most serious difficulty has been the scarcity of water.

The gold is in the form of coarse and scarcely water-worn wire and flat scales, just as it came from the vein (Yung and McCaffery, p. 362). Jones (p. 22) wrote that the largest nugget reported was worth $3400 but warned that "the size of the nugget thus obtained is much to be doubted." He stated that the fineness is about 918. Dr. F. A. Wislizenus analyzed placer gold from the New Placers in 1846 and was cited by Northrop (p. 264):

Gold	Silver	Iron and. Silica	Total
92. 5	3.5	4.0	100.0

Northrop (p0 264) stated that the analysis was repeated by Blake (1856, p. 94) and by Stevenson (1881, p. 399). Northrop added that "according to Dale Carlson (memo., Oct. 5, 1953), some coarse nuggets in the New Placers district have cavities lined with wires and crystals."

Lead-Zinc

Lead-zinc deposits are restricted to the southwestern corner of the San Pedro Mountains and are found only in the Madera Limestone.

Most of the deposits are a few feet wide and as long as 1000 feet in the outcrop. The ore appears to have replaced certain favorable beds, and the deposits are usually no deeper than the thickness of the bed.

The small deposits have the shape of veins, but the large deposit at the Carnahan mine (formerly Lincoln—Lucky mine) is an ore pipe. In the ore shoots, the pipe is elliptical in cross section; elsewhere it is tabular. The veins belong to a set which strikes from N. 75° E. to N. 90° E., the most frequent strike being about N. 80° E.

At the surface many of the veins are capped with gossan, which could be traced as far as 1000 feet in one instance. It is difficult to determine the original condition of the veins from their present oxidized condition, but several reports by early investigators are available.

The best lead-zinc deposit is at the Carnahan mine. Yung and McCaffery (p. 357) wrote that the primary ore is composed of galena, sphalerite, alabandite, marcasite and pyrite, with a small amount of chalcopyrite. Lindgren et al. (p. 172) added that quartz and calcite are the gangue minerals. The quartz observed by this writer was fine grained and massive, with vugs containing quartz crystals up to 1 mm long and 0.2 mm across. Fluorite was observed at one prospect, and Northrop (p. 243) mentioned that it was found at the village of San Pedro. Northrop also listed traces of argentite from the Carnahan mine.

Northrop cited a number of oxidized minerals from the lead-zinc deposit s. Anglesite, cerussite, botryoidal hematite, limonite, possibly minium (Pb_3O_4), pyrolusite, and native silver are listed from the Carnahan mine, and cerargyrite is listed from the Jackson mine. Northrop credited Dale Carlson for discovery of the minerals listed from the Carnahan mine. Abundant kaolin is also present in the upper portions of this mine.

This type of deposit has not been very important commercially, according to Yung and McCaffery (p. 357). The oxidized ores in the Carnahan mine contained a little zinc as hemimorphite, but oxidized lead and silver minerals were most important in the upper parts of the veins. Galena and sphalerite were important in the Carnahan mine in unoxidized ore below the water table. A few tons of manganese oxides were mined after World War II.

Iron

Iron occurs in veins and bedded deposits, as magnetite and specularite, and as hematite and limonite derived from the oxidation of pyrite.

Most of the iron deposits have been prospected for gold, but some iron has been mined for a flux. The deposits are small and will probably not be economically important in the future.

Deposits containing magnetite and specularite are clustered around the stocks with but few exceptions. There is no apparent relation between the distribution of the deposits and dikes and sills. Deposits containing magnetite alone are generally closer to the stocks than those containing specularite alone, whereas deposits containing both magnetite and specularite occupy an inter-mediate position. Most of the deposits lie in a northeasterly-trending belt which contains the four stocks at the eastern end of the mountains. A few deposits are adjacent to the stock in Old Timer Gulch. Specularite occurs in the garnet beds in which the deposits at the San Pedro mine occur. This is the principal occurrence of specularite away from the stocks.

Veins containing limonite and hematite derived from the oxidation of pyrite are important for their gold and have been discussed under gold deposits. Most of these veins do not contain much iron.

Few of the veins containing specularite and magnetite are well exposed, and the size and attitudes of most of the veins could not be determined. One specularite vein which has been mined occupies a fault which is within and follows a rhyolite dike. A stope in a swell in the vein which is accessible is approximately 6 feet wide, 15 feet long, and 10 feet high.

The mineralogy of the veins is simple. Most of the veins contain magnetite, specularite, and quartz. Apparently pyrite was present in all the iron veins. Several prospects contain pyrite, while others contain goethite pseudomorphs after pyrite, quartz boxwork, or limonite gossan, which indicate the former presence of pyrite. Most of the magnetite is fine grained, but some very coarsely crystallized magnetite occurs in two veins along the northern side of the Oro Quay stock. The crystals range from one-fourth inch to two inches across. The ore appears to have been about 50 percent pyrite and contains neither quartz nor specularite. The specularite vein mentioned above contains specularite with goethite pseudomorphs after octahedral pyrite crystals, some small quartz crystals, and some malachite.

Bedded iron deposits have originated through contact metamorphism and metasomatism of certain favorable beds. These magnetite deposits usually have an elongated lens shape and are limited to single beds. Within a deposit the ore is usually spotty, with occasional rich concentrations of magnetite Specularite occurs in many metamorphosed beds but is never concentrated enough to mine. Magnetite crystals with a dodecahedral habit are peculiar to the metasomatic deposits.

Magnetite and specularite occur in medium-grained epidote-rich hornfels, which appears to have been derived from an argillaceous sandstone. Fine tremolite needles, and green and colorless chlorite are common accessory minerals.

A small magnetite deposit on the eastern side of Oro Quay Peak is of particular interest, since it appears to be of contact metamorphic origin. The stock is in contact here with the lime-stone of the San Andres Formation, which is somewhat dolomitic at this place. Fine-grained magnetite is associated with pyrite, malachite, chrysocolla, serpentine, finely fibrous tremolite, and crystalline calcite. The serpentine, tremolite, and calcite have originated from the contact metamorphism of the dolomitic limestone.

ORIGIN OF ORE DEPOSITS

The ores of the San Pedro Mountains have been deposited by fluids emanating from the intrusions. The copper and magnetite deposits have formed as a part of metasomatic processes, while the gold, lead, and zinc have been deposited as fissure fillings. Localization of ore bodies is due to structural controls and favorable properties of various rock types.

The specific intrusions responsible for certain ore deposits are not always clear. The deposit at the San Pedro mine may have arisen from the dike cutting through San Pedro Mountain, from the stock in San Lazarus Gulch, or perhaps from the stock at Oro Quay Peak.

Arching of the sediments by laccoliths has probably been the most important structural control for ore deposition. The San Pedro mine deposit occupies a slight anticline above the edge of a tilted laccolith. Other Jess important, copper deposits lie in the broad arch above the laccolith and may occupy the crests of other gentle anticlines.

Gold and lead-zinc veins occupy fractures which developed at the time of intrusion or before. A few gold veins occupy fractures in the igneous rocks.

Favorable rock types have been at least as important as structural controls. Limestone was particularly susceptible to replacement by ore and tactite. Rhyolite sills at the top of the Madera Limestone forced rising solutions to pass through the limestone. Fracturing took place in hornfels strong enough to hold fissures open, thus providing abundant channelways for the deposition of gold ore. In contrast, the stronger rhyolite did not yield many open fissures. The pressures exerted during the late stages of intrusion of the monzonite stocks were sufficient to open within them some fissures which were subsequently mineralized.

Areas in the immediate vicinity of the larger stocks were within reach of the hydrothermal solutions but do not contain important mineral deposits. Such areas did not have favorable conditions for the deposition of ore. The most important condition of all is probably an easily replaceable limestone up-dip from a stock. Such a condition does exist where the Madera Limestone abuts the stock, but possible mineral deposits formed in this manner are not exposed.

Lateral hydrothermal zoning outward from the stocks is evident in the San Pedro Mountains (pl. 3), Magnetite veins are within or adjacent to the stocks. The veins containing specularite are, in general, farther from the stocks. The metasomatic copper deposits are also farther from the stocks but are somewhat closer than the lead-zinc deposits.

NONMETALLIC DEPOSITS

Quartz Sand

The Glorieta Sandstone of the San Andres Formation on the southeastern slope of the San Pedro Mountains is unusually friable and clean. At present it is being mined in a small way.

Garnet

It has been stated above that certain garnet beds are more than 150 feet thick near the San Pedro mine. If demand were great enough, garnet might be mined cheaply in surface cuts. In some places that are barren of copper minerals, the garnet appears to be very pure, with little quartz or calcite.

At present such garnet is used only as an abrasive. However, garnet mines in production elsewhere in the country are able to supply industry with sufficient garnet for many years. Perhaps a new use will have to be found before garnet is produced from San Pedro Mountain.

Limestone

Limestone has been quarried to a limited extent from several places for use in smelters and as a building stone. The various beds of the Madera Limestone appear to be uniform in texture and color. Limestone from any place in the stratigraphic section would probably be equally suitable for future needs.

WATER SUPPLY

Water is rather scarce in the San Pedro Mountains. There. are no springs and the streams are only ephemeral. Wells drilled in the surrounding plains reach water at a depth of 500 to 800 feet, and it rises to within 100 to 200 feet of the surface (Wells and Wooton, p. 20). A well at the mouth of San Lazarus Gulch reached water at 400 feet, and it rose to a level 125 feet below the well head (Lindgren et al., p. 175). The groundwater level in the Carnahan mine is about at the top of the sulfide ore, which is roughly 400 feet below the surface (Smith et al., plate 10).

Water may be obtained from several wells and three mine workings, in addition to those listed. A well at the Baca ranch on the southern side of the mountains is being used at present. A well at the former Perry camp, in the northeastern part of the mountains, has its original casing, and water is in the-'bottom. At the Old Timer mine the well still has the original pump. One other well is located about 200 yards southwest of the ruins of San Pedro village, but its condition is not known. A shaft on the eastern side of San Lazarus Gulch reaches the water level. On the eastern side of Old Timer Gulch, above the Old Timer mine, two tunnels reached the water table not more than 100 feet below the surface. In one mine, a vein was stoped above and below the tunnel level about 200 feet from the portal. Water seeps from the back (roof) of the stope and stands in the stope within four feet of the tunnel level.

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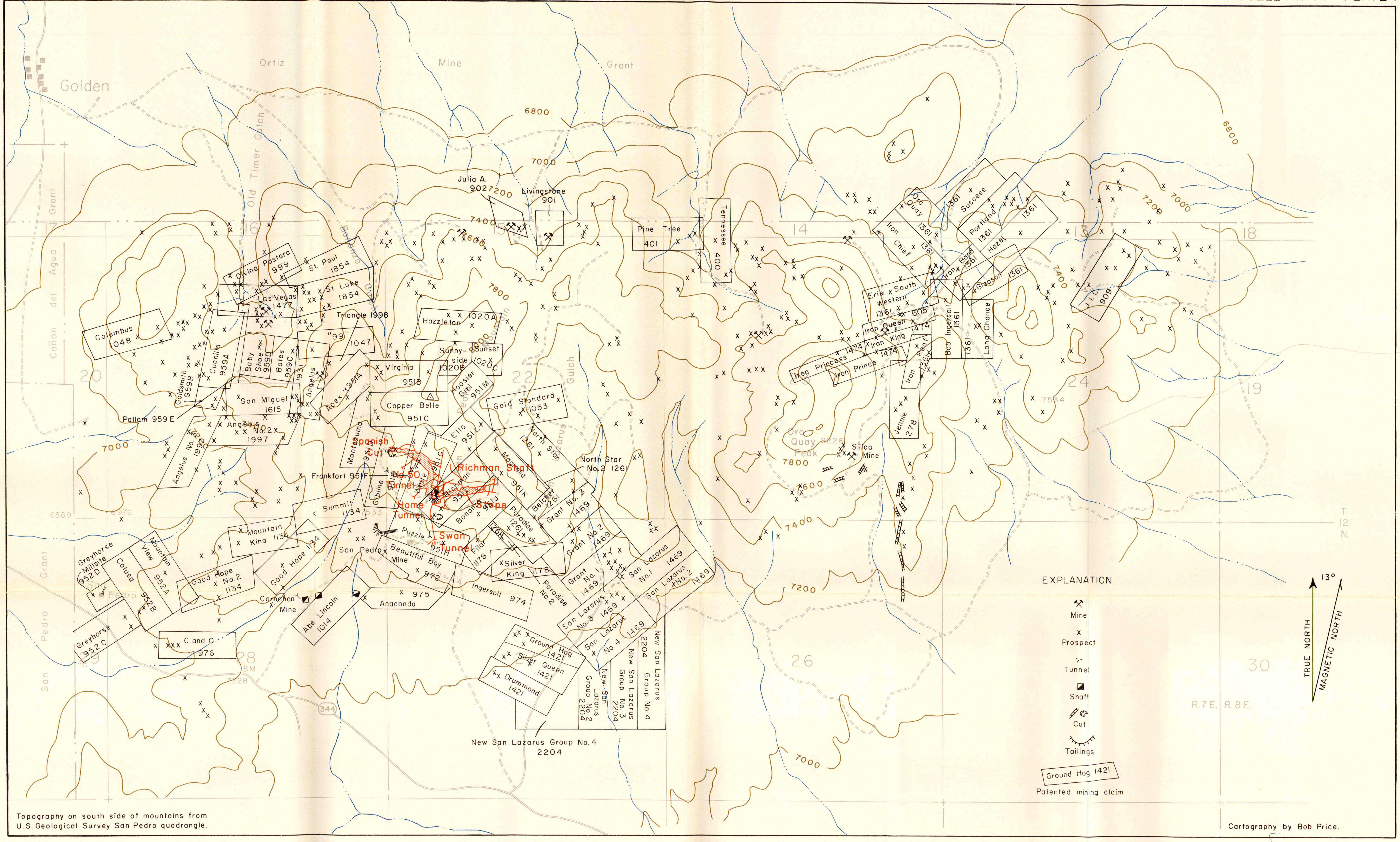
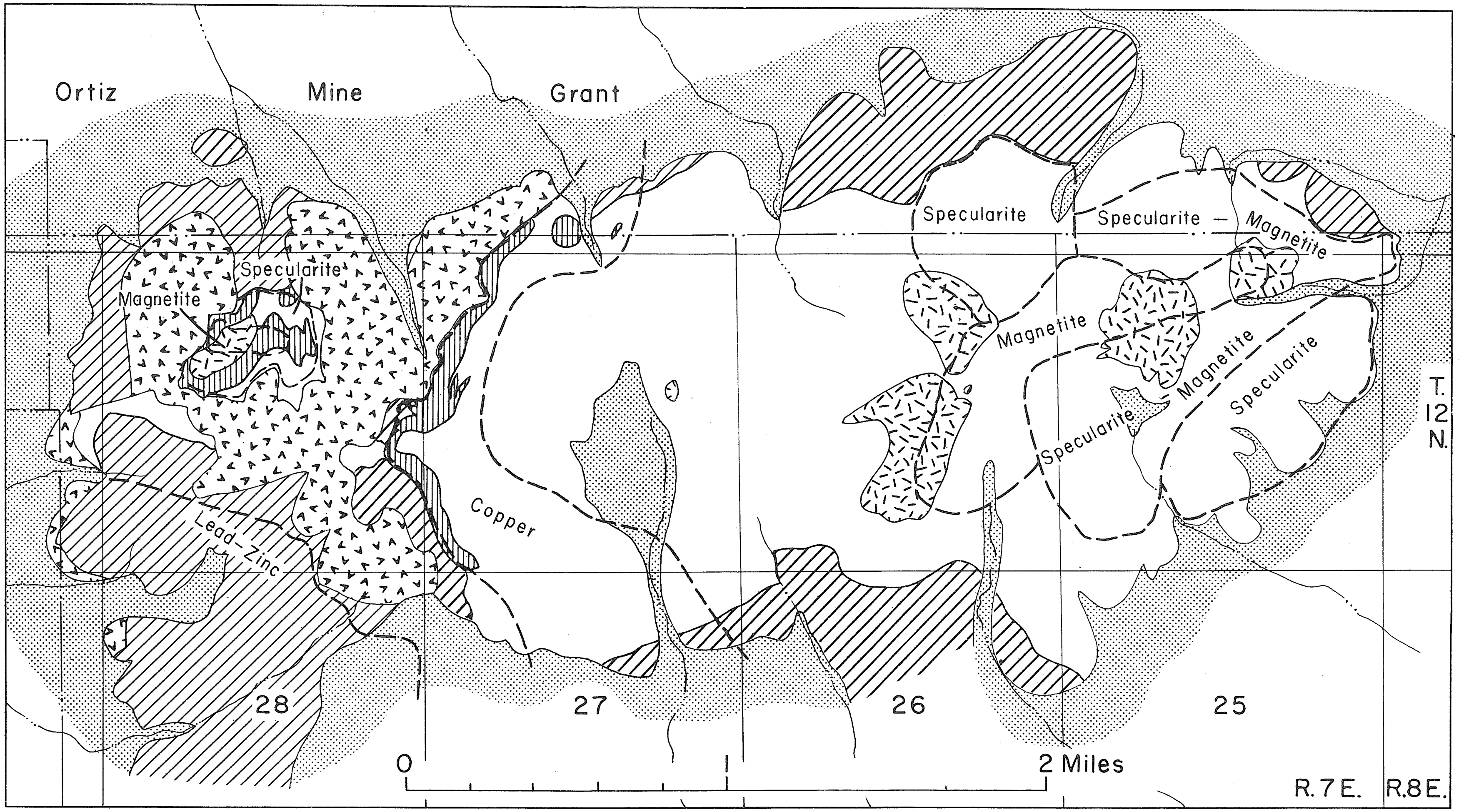


TOPOGRAPHIC MAP OF THE SAN PEDRO MOUNTAINS, SANTA FE COUNTY, NEW MEXICO

Scale 1:15,840

1.0 .5 0 1 Mile

Contour interval: 200 feet
Datum is mean sea level



EXPLANATION

Stocks and pipes

Alluvium

7

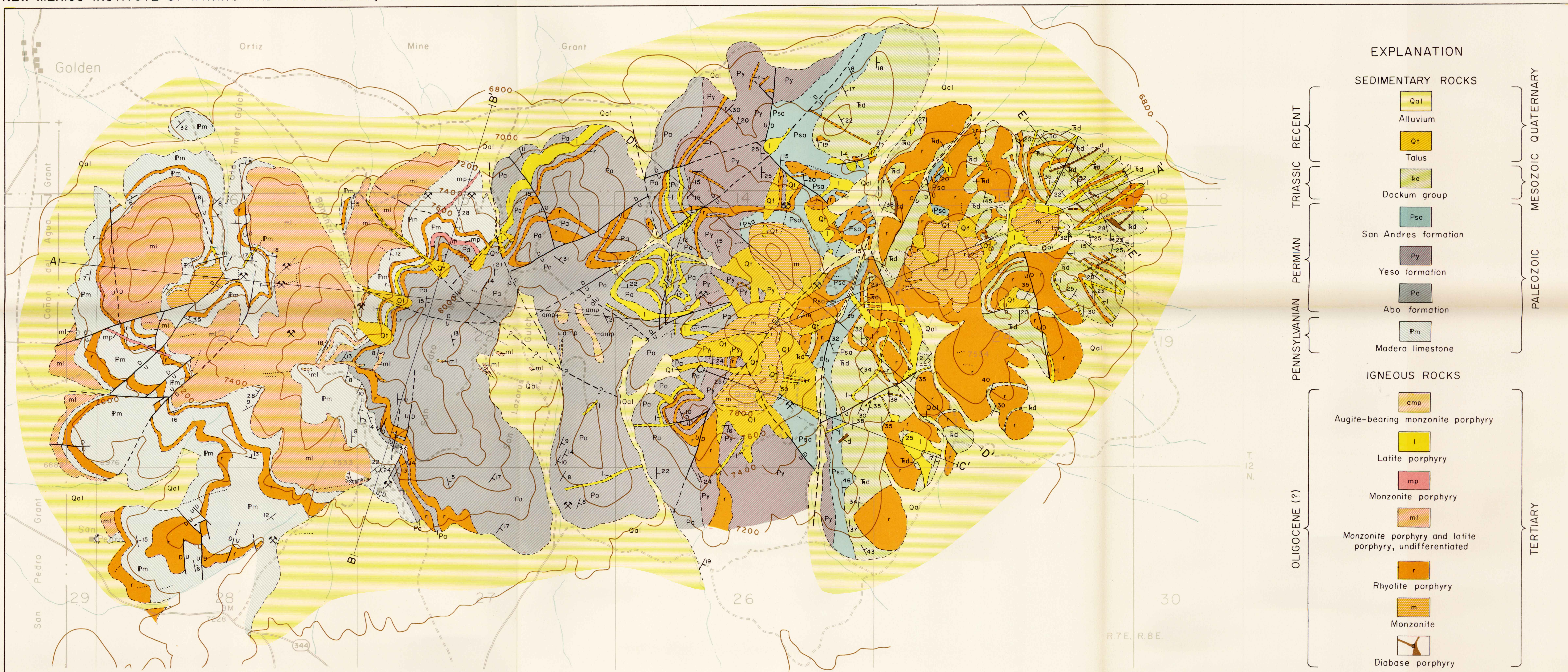
Unmetamorphosed rocks

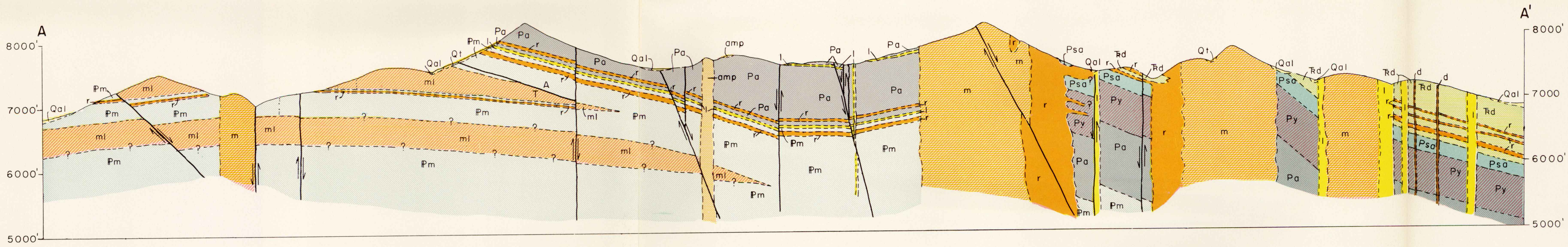
Laccoliths

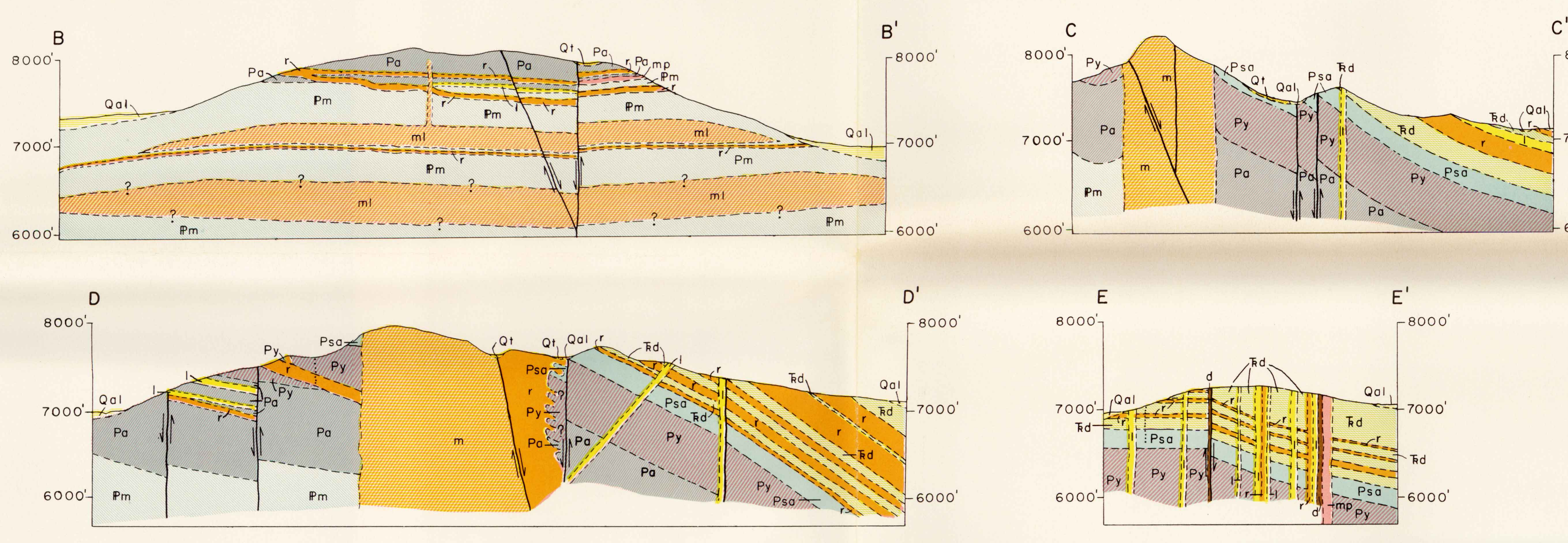
Tactite

Isograd bounding hydrothermal zones defined by characteristic mineral deposits

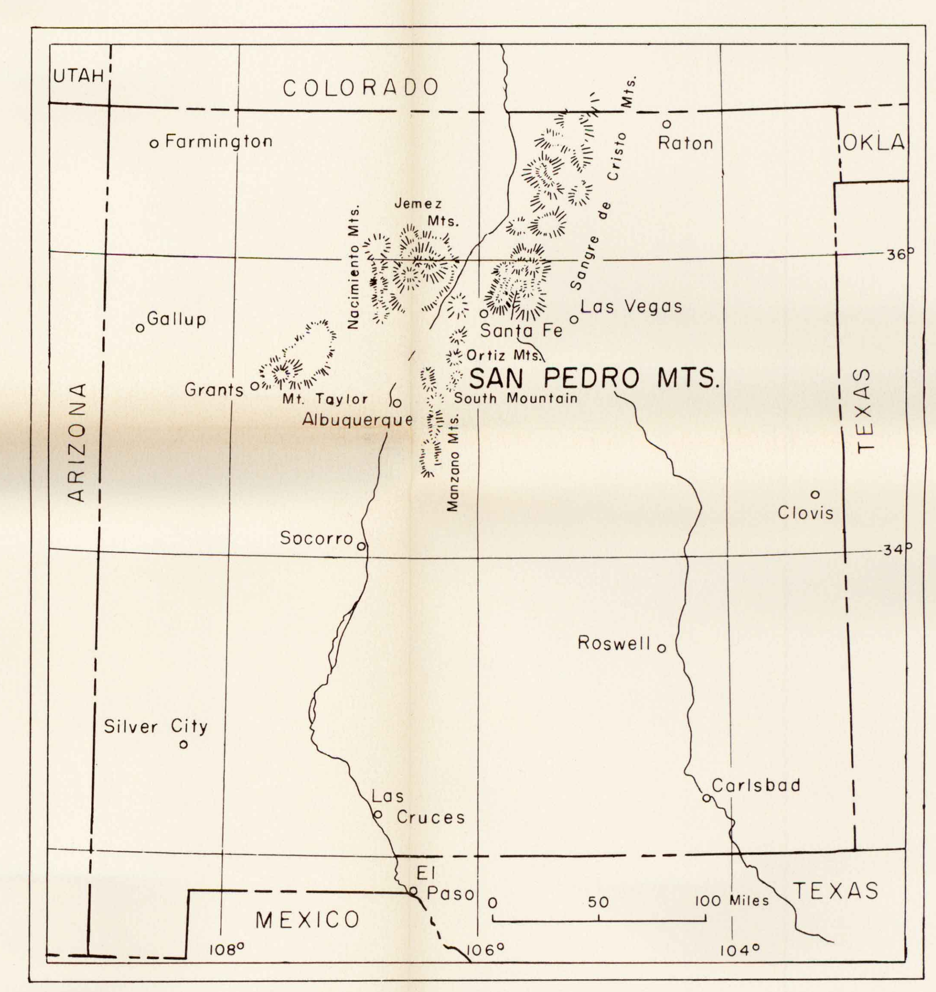
METAMORPHISM AND HYDROTHERMAL ZONING IN THE SAN PEDRO MOUNTAINS



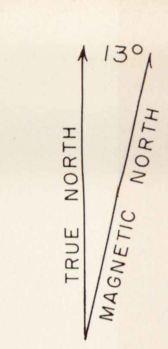




Base adapted from U.S. Geol Survey San Pedro quadrangle, S.C.S. planimetric sheets N.M. 156 and N.M. 180. Contours on north side of mountains constructed from aerial photographs.



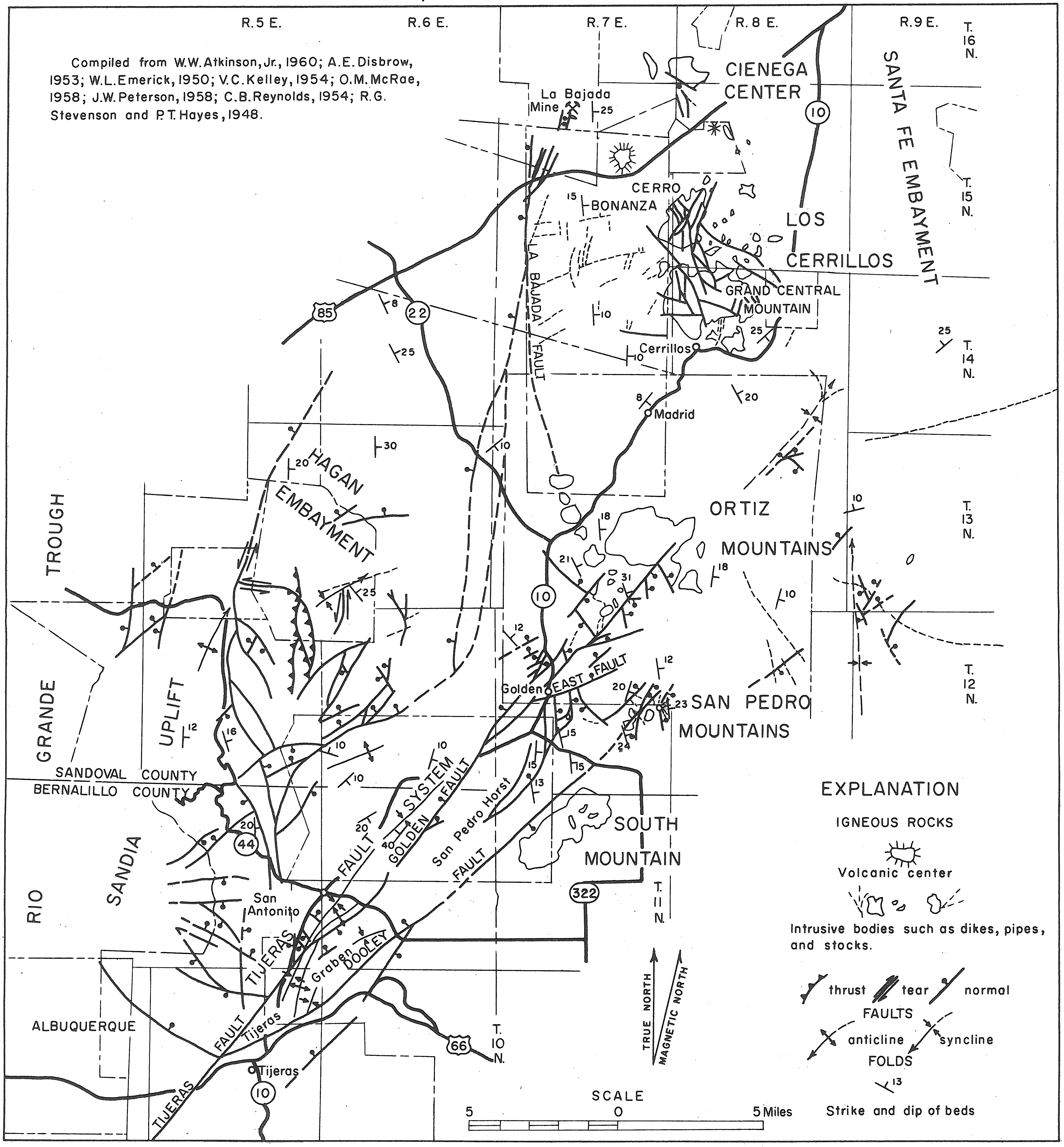
Index map of New Mexico showing location of the San Pedro Mountains



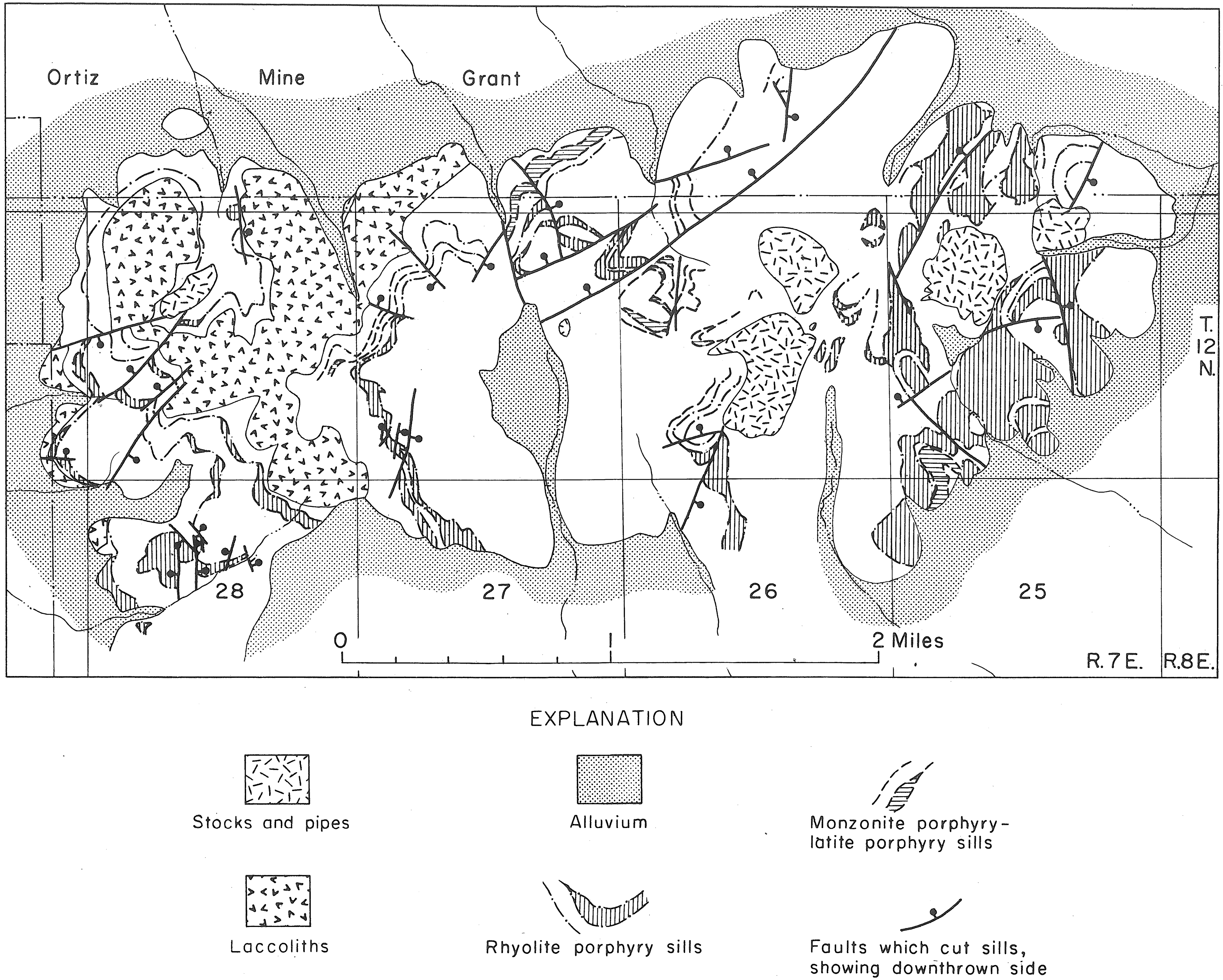
Approximate mean declination, 1954.

Cartography by Bob Price

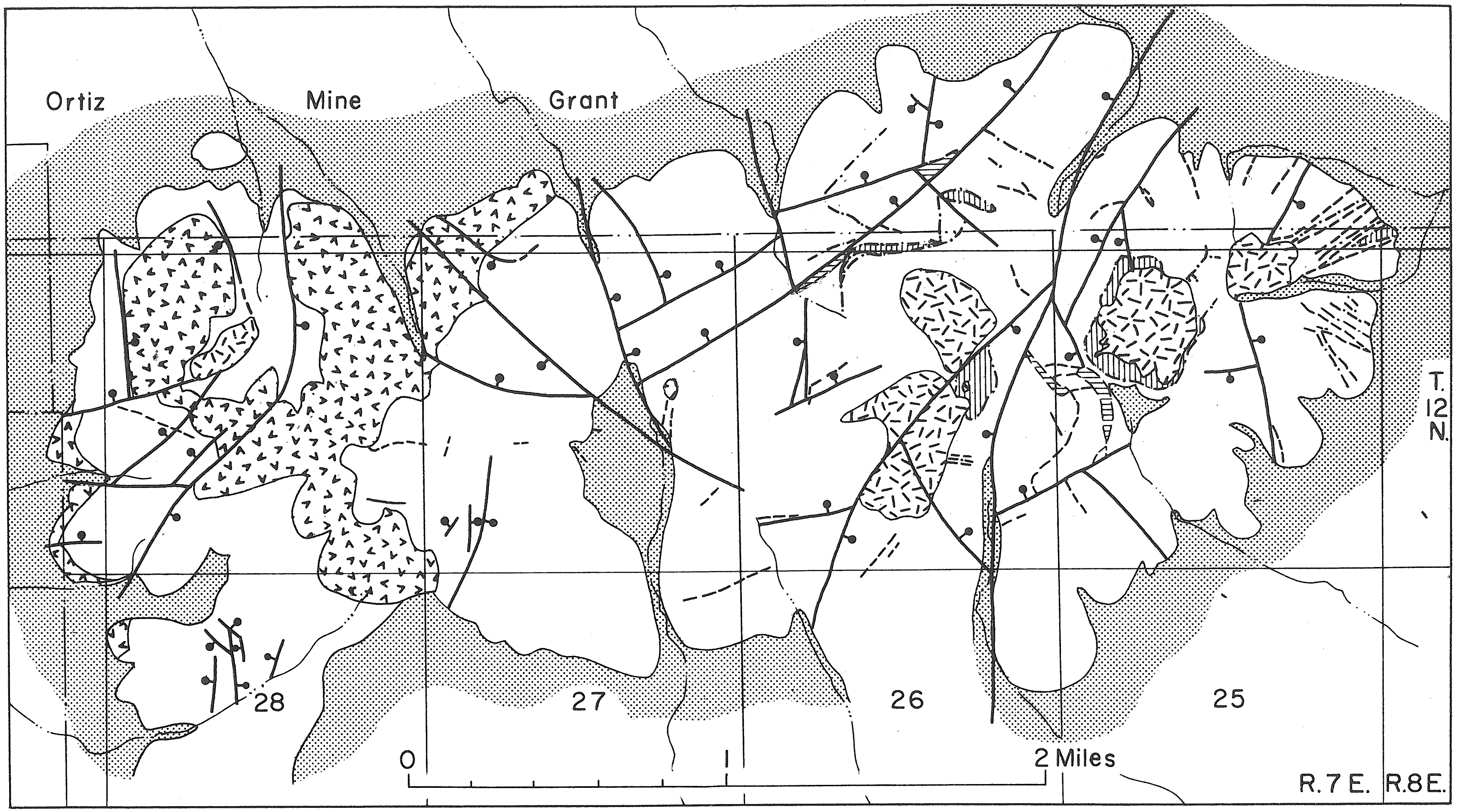
GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE SAN PEDRO MOUNTAINS, SANTA FE COUNTY, NEW MEXICO

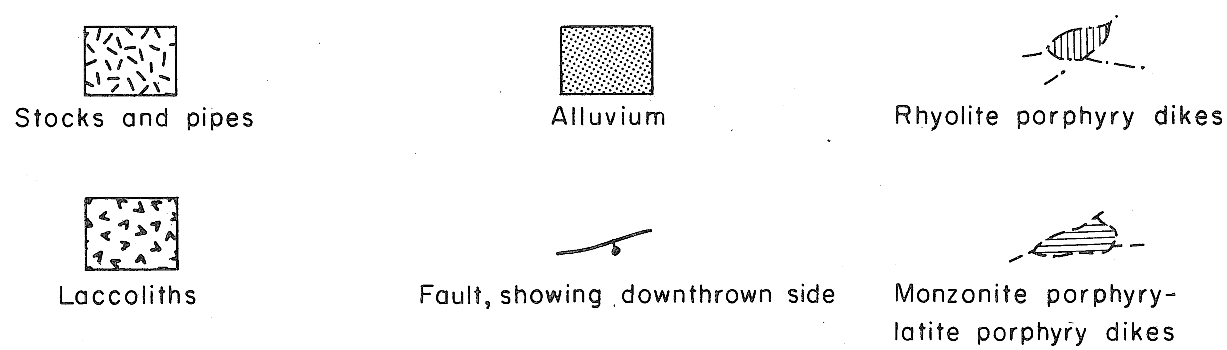


TECTONIC MAP OF THE SAN PEDRO-ORTIZ PORPHYRY BELT

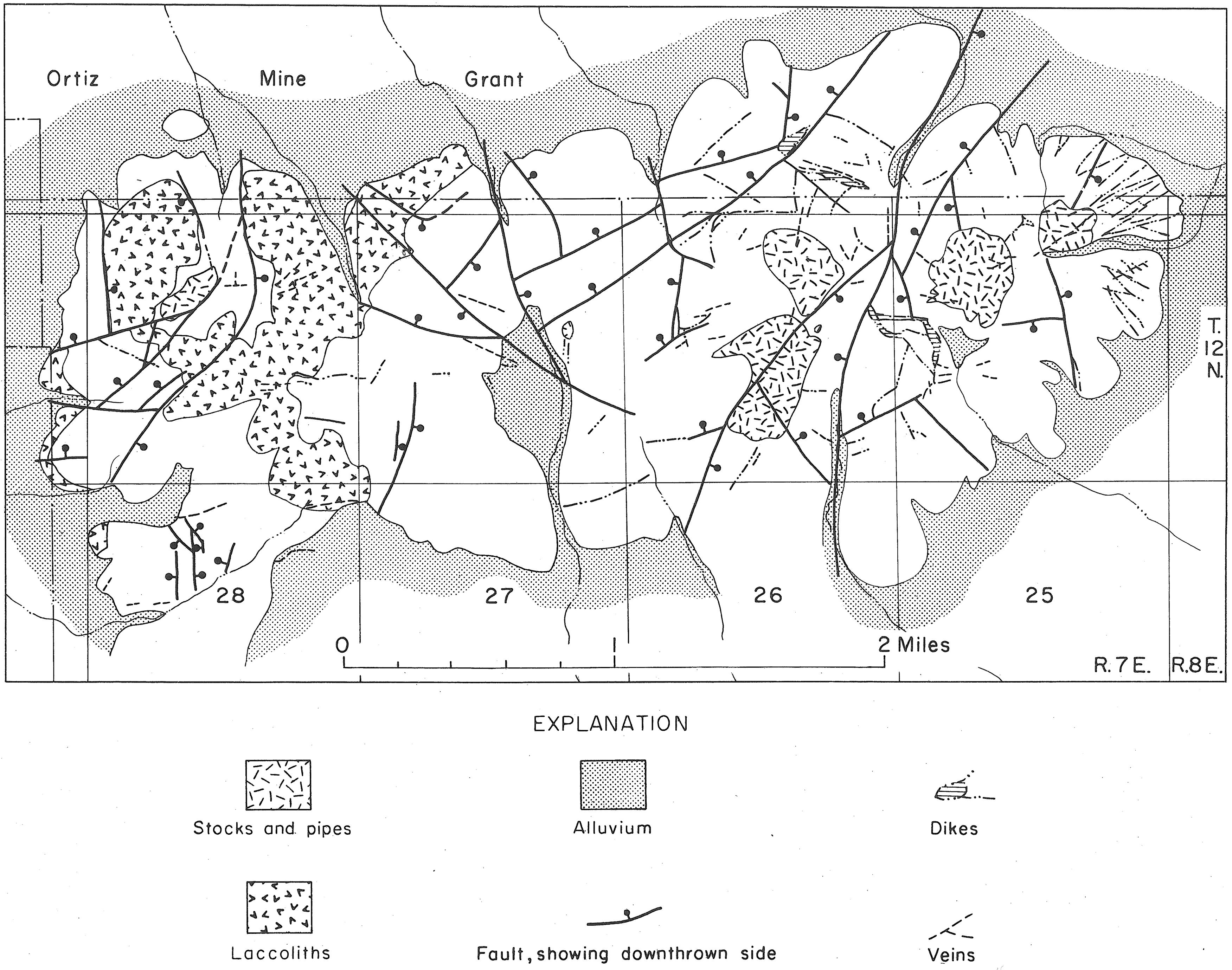


DISTRIBUTION OF SILLS IN THE SAN PEDRO MOUNTAINS





DISTRIBUTION OF DIKES IN THE SAN PEDRO MOUNTAINS



FRACTURE PATTERN IN THE SAN PEDRO MOUNTAINS