THE GEOLOGY AND ORE DEPOSITS OF THE
HELMET PEAK AREA, PIMA COUNTY, ARIZONA

by

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A Thesis
submitted to the faculty of the

Department of Geology
in partial fulfillment of
the requirements for the degree of

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in the Graduate College
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By

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INTRODUCTION

Acknowledgments

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For the information concerning some of the mines in the area, the writer is indebted to the following persons: to Dr. G. M. Butler for the Plumed Knight group and the Gray Copper mine; to Dr. W. H. Brown and Mr. S. Adams for the San Xavier mines; to Mr. Joseph Flannery and Mr. Henry Mayer for the Olivette and Korda groups; to Mr. J. Pemberton for the Mineral Hill group; to Mr. L. M. Lawson and W. T. Lawson for the Paymaster group; and to Mr. Ralph King for the Helmet Peak Mine. Mr. Jesus Ortiz, a resident in the area, assisted the writer on several occasions.

A portion of the Pima Mining District Claim Map is incorporated in this thesis through the courtesy of Mr. T. N. Stevens, U. S. Mineral Land Surveyor. Mr. J. V. Monfort assisted the writer on a few occasions in the field.
Previous Works on the Region

In 1921, Dr. F. L. Ransome wrote a short paper on the "Ore Deposits of the Sierrita Mountains, Pima County, Arizona," which was published in the United States Geological Survey Bulletin No. 725. The object of the paper was to make a reconnaissance study of the entire Sierrita Mountain district, of which the Helmet Peak Area is a part, in order to determine the advisability of undertaking a more detailed study in the future. He made a brief description of the different mines in the Helmet Peak area and their general geology.

N. H. Darton, in his "Resume of Arizona Geology" published by the Arizona Bureau of Mines in Bulletin No. 725, 1925, devoted a few paragraphs on the area, but his data were quoted mostly from Ransome's work mentioned above.

In 1929, Charles F. Park, Jr. wrote a thesis on the "Geology of the San Xavier District," two copies of which are now available in the University of Arizona library. This work is incorporated in the present study with some changes in the stratigraphic and structural interpretations.

In 1930, Edwin B. Eckel submitted a Master's thesis to the University of Arizona on the "Geology and Ore Deposits of the Mineral Hill Area, Pima County,
Arizona," two copies of which are also available in the University library. This work is also incorporated in this thesis with major changes.

Other works in the area are in the form of old unpublished mining reports some of which are available to the writer through the courtesy of the men mentioned in the acknowledgments. Some reports date as far back as 1905 and as late as 1929.
Fieldwork and Laboratory Studies

Geologic mapping of the area was done mostly on week-ends during the school year of 1940-41. The work was resumed from December 1941 to February 1942. Most of the laboratory work was done during the months of February, March and April 1942.

The topographic map used in this work is from the United States Geological Survey topographic sheet of the Twin Buttes Quadrangle. Geologic data were plotted with the aid of a Brunton compass using the three-point intersection method. Due to the relative flatness of the area, an aneroid barometer was not used.

Thin-sections of rocks and polished sections of ore minerals were made and examined in the laboratory. Fossils were collected and identified. Minerals were determined by standard methods.
The area is about 22 miles south of Tucson along the Twin Buttes road. The road is a good automobile and truck road paved for about ten miles to the San Xavier Mission, and a well-graded dirt road, which passes through the Helmet Peak area and meets the Tucson-Nogales highway farther south, covers the remaining distance.

An alternate route is via Sahuarita, a small unincorporated town 20 miles south of Tucson along the Tucson-Nogales highway (U.S. 89). A five-mile dirt road leads west from this settlement to a point about two miles south of the Helmet Peak area along the Twin Buttes road. Sahuarita is on the Tucson-Nogales railroad line of the Southern Pacific and it is the nearest shipping point to the region.

The elevation in the area ranges from 3400 feet to 4000 feet. Roads and trails traverse the area in every conceivable direction.

Mapping was confined to Sections 33, 34, 35, and 36 of Township 16 South Range 12 East; and to Sections 1, 2, 3, 4, 9, 10, 11, 12, 13, 14, 15, 16, 21, 22, 23, and 24 of T 17 S R 12 E. The area covers about twenty square miles.
Fauna and Flora

Vegetation is of the desert type of southern Arizona. Palo Verde, mesquite, yucca, and several varieties of cactus are the most abundantly represented.

No wild animals, except a few coyotes and several rabbits, were seen by the writer during his work, but wildcats were reported to be present in the area.

Climate

The climate is the semi-arid type of southern Arizona. The average annual rainfall is about ten inches; most of it falls during the summer. Field work is possible throughout the year. The winters are not severe and most of the days are sunny and comfortably warm. Due to the higher elevation of the area, the summer temperatures are five to ten degrees cooler than those of Tucson. The minimum temperature is about 20°F and the maximum is 110°F.
Settlement

More than half a dozen houses, remnants of the old mining days in the San Xavier sub-area, are now occupied by several Mexican families forming a small village settlement. A one-room school house with about 12 to 15 pupils is being conducted in the village under one school teacher. Some of the houses in the area can be repaired for future use.

Water Supply

Domestic water supply for the settlers in the San Xavier village is obtained from the shafts of the Empire Zinc Co. Most of the shafts in the area are filled with water to within 200 feet or less from the surface. In spite of this, however, the problem of adequate water supply for any mill operation in the area will be difficult to solve and may greatly affect the future possibilities of the area.
Topography

The area is in the northeastern part of the Sierrita mountain system, one of the smaller of the nearly meridional mountain ranges of southern Arizona. The Sierritas separate the Altar valley in the west from the Santa Cruz valley on the east. The range is between thirteen to fourteen miles long and roughly four miles wide. Apparently no part of the range rises more than 2,000 or 3,000 feet above the upper margin of the flanking desert plains or attains an altitude greater than 6,500 feet above sea level. In comparison with the Santa Rita mountains to the east or to Baboquiviri Range to the west, the Sierrita mountains are low and are scenically unimpressive.

In general, the prominent topographic features in the area consist of cliffs or steep hills of the Paleozoic rocks; whereas, the lowlands are underlain either by coarse-grained igneous rocks, the less resistant Cretaceous series, or the soft gypsiferous member of the Paleozoic beds. Helmet Peak, which rises about 550 feet above the surrounding flats, consists of the resistant, cliff-forming Snyder Hill limestone. The peak

is the most prominent landmark in the area. The high elevations of the San Xavier and the Mineral Hill areas are made of the Paleozoic limestones, quartzites and hornfels, whereas the depressions and saddles within these areas are underlain by the soft, non-resistant gypsiferous and marly series of the Permian beds.

Surrounding the prominent physiographic features mentioned are rolling hills and gentle undulating plains cut by shallow washes and arroyos which drain toward the Santa Cruz valley to the east. The plains are composed almost entirely of alluvial detritus, but, as is characteristic of the pediments in Southern Arizona, the alluvium is thin. The plain areas and depressions are underlain by granite or by coarse arkose; whereas the rolling, rounded ridges are made of volcanics, quartzites, and brecciated rocks of the Cretaceous series.

As a whole, the Helmet Peak area is relatively flat with a few gently rolling hills rising not more than 450 feet above the plains.
Development of the Topography in the Area

Differences in the resistance of the formations have entirely controlled the physiographic features of the Helmet Peak area. Rocks composed of several minerals are greatly affected by weathering and erosion, while the more simple rocks like limestones and shales are less affected. Typical of the semi-arid conditions, weathering agents tend to disintegrate rocks of non-uniform mineral composition such as granite. This is due to the difference in expansion and contraction of the individual mineral grains in the rock caused by changes of temperature between day and night or the change due to summer showers. Sudden rainfall during the hot summer days rapidly cools the rock, thereby promoting sudden contraction of the individual minerals, a process that greatly weakens the rocks. The same is true of the change from summer to winter. As a result of these processes of weathering the granite rocks have been eroded to an undulating plain.

On the other hand, precipitation under arid conditions is insufficient to dissolve limestone at the same rate that erosion removes and disintegrates the coarser igneous rocks. Its homogeneity in mineral composition makes it possible for its constituent
minerals to expand and contract uniformly thus maintain­ing a stronger resistance to torrential downpours than the igneous rocks. The same is true of the shales in the area. As a result, the limestone, and shales stand as ridges and escarpments while the coarser igneous rocks constitute the lower areas.

The Permian gypsiferous formation has low resist­ance to erosion. These beds show variable mineral com­position and consist of marls, impure limestones, weak shales and gypsum. Wherever present, these beds form valleys and gentle slopes.

The arkoses and sandstones behave somewhat like igneous rocks. The weakness, however, is more due to incomplete cementation of the grains than to hetero­geneity of their composition.

Quartzites behave like limestone beds, because of their relatively homogeneous composition and strong induration.

Differences in mineralogical composition and degree of consolidation of the rocks do not entirely account for the development of the topography in the area. Many valleys follow fault zones along which the rocks are crushed and easily eroded.
SEDIMENTARY ROCKS

General Statement

The presence of the following Paleozoic formations in the area has been established by the present writer: the Cambrian Bolsa and Abrigo formations, the Devonian Martin limestone, the Mississippian Escabrosa limestone, the Pennsylvanian Naco formation, the Permian Manzano and Snyder Hill formations.

In the Mineral Hill sub-area, the stratigraphic column includes the formations from the Cambrian Bolsa quartzite to the Permian Manzano formation. The Snyder Hill Formation was not recognized in this locality.

The Paleozoic section in the San Xavier hills includes formations from the Mississippian Escabrosa limestone to the Snyder Hill Formation. Cambrian and Devonian beds were not found in this locality.

The Cretaceous strata in the area have been divided into three units: (1) Volcanic Series, (2) Recreation Red Beds, (3) White Arkose. Most of the Cretaceous beds crop out south of the San Xavier hills.
CAMBRIAN

Bolsa Quartzite

The Bolsa quartzite is exposed in the Mineral Hill sub-area. It is a rusty brown to pinkish tan vitreous quartzite. Individual beds have variable thickness and some show distinct cross-bedding. The upper beds are dark and micaceous and probably represent silty facies of the formation that has undergone some metamorphism. The rest of the quartzite varies from fine sandy beds to almost conglomeratic near the base.

The total thickness in the area is about 1,300 feet. No fossils were found. Recognition of the formation is based on lithology and stratigraphic position.

In other areas1 in southeastern Arizona, the Bolsa quartzite is overlain by the Pima sandstone and by the Cochise formation. Due to the poor surface exposures and extensive metamorphism of the rocks, the presence of these two formations above the Bolsa quartzite in the Helmet Peak area could not be ascertained. It is possible, however, that the upper part of the formation mapped as Bolsa quartzite represents the metamorphosed equivalent of the Pima sandstone and the

In the literature, Stoyanow described the Cochise formation. The great thickness of the Bolsa quartzite in the area lends weight to this belief.

Dr. A. A. Stoyanow has correlated the Bolsa quartzite with the Wheeler formation of the House Range Section in Utah.

Abrigo Formation

In the Bisbee Quadrangle, Ransome\(^1\) described the Abrigo limestone as thin-bedded Cambrian limestone with conspicuous laminated structure produced by alternation of irregular sheets of chert and gray limestone. The total thickness is about 380 feet. The Abrigo formation has also been located in the Whetstone Mountains, Cochise County, between Benson and Tucson; in the Picacho de Galera Hills, Pima County, 25 miles west of Tucson; in the Santa Catalina Mountains, Pinal County, 30 miles north of Tucson; and in the Santa Rita and Empire Mountains, across the Santa Cruz Valley from the Helmet Peak area.

The formation is exposed at Mineral Hill sub-area. It is extensively metamorphosed due to hydrothermal alterations caused by later intrusives. Few open cuts within the formation show remnants of what appear to be the original wavy layers of chert protruding above the limestone beds. This character, however, does not seem to be as prominently developed in the area as in other districts of southeastern Arizona. This is probably due to the extensive silicification of the beds.

Fossils were not found in the formation, and

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\(^1\) Ransome, F. L.\textemdash Geol. and Ore Deposits of Bisbee, Quadrangle, Arizona. U.S.G.S. Prof. Paper No. 21, (1904), p. 30-33.
identification was based on stratigraphic relations and lithologic character.

In the Bisbee area and other localities where fossils were found, the fauna is of early Upper Cambrian age. The following fossils were identified in the Abrigo formation of Bisbee: *Tricrepicephalus texanus* and *Hesperaspis butleri*. The formation has been correlated with the Weeks formation of the House Range Section, Utah.

The standard Upper Devonian formation of southeastern Arizona is the Martin limestone established by Ransome. In the Bisbee-Tucson sub-area, the Martin limestone is a dark-gray compact formation with some lighter colored layers.

In the Mineral Hill sub-area, the Martin limestone, about 250 feet thick, overlies the Abrigo formation disconformably. The thickness of individual beds ranges from one to two feet. The unmetamorphosed portions of the Martin limestone are dark-gray, compact and fairly pure limestone. Near the base, the formation has been extensively metamorphosed by later intrusives. A white, fine-grained, sugar-textured, marbleized limestone is produced by metamorphism.

The only fossil found was Cladopora limitaris (Rominger). This is a branching colonial coral similar to Favosites. The genus Cladopora is characterized by the non-uniform thickness of the walls of the coral, whereas Favosites is characterized by the uniform thickness of its walls. This species is intermediate between the two genera, that is, the walls of the individual coral are slightly thickened, but not as pronounced as

in the typical Cladopora. For this intermediate type of coral Rominger\(^1\) used the name *limitaris*.

At Bisbee the faunal assemblage of the Martin limestone is rather prolific. It has been correlated with the Hackberry shale of Iowa by H. S. Williams\(^2\).

The content of this discussion in the original text is

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LOWER MISSISSIPPIAN

**Escabrosa Limestone**

Like the Bolsa, the Abrigo and the Martin formations, the presence of the Escabrosa limestone in the Helmet Peak area was not recognized by previous workers. The presence of this limestone in the Helmet Peak area has been established by the writer. The lithology and other characteristic features of the limestone are very similar to the equivalent beds in other areas of southeastern Arizona. The Escabrosa is a cliff-forming, massive, thick-bedded granular limestone. Except for some cherty beds, it is a relatively pure limestone and free from dolomite. The colors vary from almost pure white to gray with some portions showing pink tints. Some beds are made almost entirely of crinoid plates. Nodules and irregular bunches of chert are not uncommon. Large calcite rhombohedrons, many of them distorted by deformation, are present. This is especially true in areas of intense metamorphism. Weathered surfaces of the Escabrosa are covered with dark brown to black sooty coatings.

The Escabrosa limestone in the San Xavier sub-area, west of the Twin Buttes highway, is repeated by numerous faults which were difficult to trace due to their tendency to produce a minimum of gouge and breccias. Fault planes
were also probably sealed by recrystallization of the limestone or by flowage during its deep burial. Clear bedding planes are rare thus making the determination of dips and strikes rather difficult. Undescribed corals, known only in the Lower Mississippian of southeastern Arizona, were found in this limestone.

The Escabrosa limestone was first described in detail by Ransome in the Bisbee quadrangle. Abundant Lower Mississippian fossils were recognized. Ransome estimated the thickness in Bisbee to be 700 feet. Enlows reported 750 feet in the Little Dragoon mountains and Johnson estimated about 700 feet at Helvetia. The writer observed 600 feet in the Empire Mountains.

LOWER PENNSYLVANIAN

Naco Formation

At present the term "Naco Formation" does not correspond to Ransome's original "Naco Limestone" which included all the formations above the Mississippian Escabrosa limestone and below the Cretaceous. This has been subdivided into several stratigraphical units. Dr. A. A. Stoyanow\(^2\) retained the name Naco only for that part of Ransome's original Naco which contains Pennsylvanian fossils.

As elsewhere in southeastern Arizona, there is a distinct difference in lithology between the Escabrosa limestone and the Naco formation. In contrast to the massive, thick-bedded Escabrosa limestone, the Naco formation is composed of thin-bedded cherty limestones interstratified with thin-bedded shales. Metamorphism has altered most of the shales to dense, tough, cherty hornstones which are rather resistant to erosion. Original bedding planes, however, are well preserved and their origin is unquestionable. Weathered surface of the shales is rusty brown with large irregular pits. The limestone members are less

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regular and persistent than the shales. The thickness of any single limestone member rarely exceeds thirty feet while the shale members are seldom over ten feet thick. Structural disturbance makes accurate measurement of the thickness of the Naco formation impossible. It is estimated to be at least 900 feet thick.

Within the equivalent formation in the Montana Mine area (Empire Mountains), Sopp reported the presence of Chaetetes milleporaceous. This fossil establishes the probable age of the formation as Lower Pennsylvanian.

Fossils are poorly preserved in the Helmet Peak area and recognition of this formation is based entirely on lithology and stratigraphic position.

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PERMIAN

Manzano Group

The lower member of the Manzano group is a series of marls, shales, limestones and gypsum which is stratigraphically above the Naco formation. The general character of these beds in the Helmet Peak area is very similar to the gypsum-bearing beds in the Empire Mountains.

Lenticular masses of gypsum are numerous and are characterized by a peculiarly weathered grayish surface. The shales interbedded with the gypsum and marls are greenish to brownish gray in color and somewhat metamorphosed. In general, they are decidedly different from the underlying Naco hornfels, being softer and less resistant. Some of the limestones in the series are grayish white but some beds show a pinkish tint in some places and bluish gray in others. The gypsum is mostly of the alabaster type. Several specimens suggest anhydrite, but they are too soft and closed-tube tests reveal the presence of water. There may be anhydrite below the outcrop but none has been recognized. The limestones interbedded with gypsum are generally softer than other Paleozoic limestones. Some greenish, cherty-looking hornstones were noted in the series interbedded with the marls and gypsum.

Conformably overlying the gypsiferous series in the San Xavier sub-area is a series of quartzites and limestones. The bottom layer is a thin bed of grayish-blue limestone about 30 feet thick. Above this limestone is a massive, rusty brown to light brown quartzite stained red in some places due to oxidation of iron. Another limestone horizon overlies this quartzite member. It is a bluish-gray, thin-bedded limestone with outlines of calcified gastropods. The second quartzite, which normally overlies the second limestone bed, is faulted out in the San Xavier hills east of the road. It is, however, present in the hills west of the road and also in the Mineral Hill sub-area. This quartzite is very similar lithologically to the lower member.

South of the San Xavier hills, on the Cretaceous flats, outliers of Manzano quartzites are apparently resting on the Cretaceous strata. Except for an intense brecciation of these blocks, the general character of the quartzites is very similar to the Manzano quartzites mentioned above. The Paleozoic quartzites, in general, can easily be distinguished from the Cretaceous quartzites; the latter being arkosic in character, whereas the former is composed practically of pure quartz. Four blocks of these outliers were mapped in the area. The quartzite block in the southern part of the area is
accompanied by limestone.

The Arizona equivalent of the Manzano formation has been briefly described by Dr. A. A. Stoyanow, in the Whetstone Mountains. He mentioned the presence of 750 feet of sandstones and shales with thin-bedded, bluish-gray limestone carrying species which occur in the Manzano group of New Mexico. Workers in the Empire Mountains and Helvetia reported the presence of the gypsiferous beds in those localities. The limestone and quartzite strata above the gypsiferous beds were first described by Alberding in the Empire Mountains.

Snyder Hill Formation

The most prominent land mark in the area, Helmet Peak, is composed entirely of the Snyder Hill formation. It is a bluish-gray, very massive, cliff-forming limestone with abundant Permian fossils. In general, the limestone is very competent and yields by flowing. This is shown by small crenulations and flow-like structure in some places. Pure calcite casts, remnants of coiled gastropods and other fossils, stand out as white spots on a very dark gray background.

Fossils recognized by the writer in this limestone were *Camaraphoria deloi*, *Composita mexicana*, *Bryozoa*, a large *Productus ofivesi* type and several other brachiopods and coiled gastropods usually observed in the limestone in other areas. The Snyder Hill formation is well known throughout southeastern Arizona. The great abundance of fossils, wherever the formation is present, makes it one of the most unique stratigraphical units. Its great resistance to erosion makes it always a prominent topographic feature. The formation was established by Dr. A. A. Stoyanow.¹ The type locality is Snyder's Hill west of Tucson.

CRETACEOUS SYSTEM

General Statement

The stratigraphic relation of the Cretaceous beds in the area is not clear as the structure is complex and outcrops are poor. The absence of a standard section that can serve as a yard stick adds to the difficulty.

In the Tucson Mountains, W. H. Brown subdivided the Cretaceous into three units: (1) the Volcanic series at the base, (2) the Recreation red beds and (3) the Amole arkose. Similar subdivision will be followed by the writer in this area.

Undifferentiated Volcanics and Sediments

A large area of Cretaceous volcanics and undifferentiated sediments is present south of the San Xavier hills. The area is broken by numerous faults which are rather difficult to trace. A detailed mapping of the structure in this area was not attempted because of the cover of detrital materials.

The series includes different types of igneous flows, predominantly rhyolites, rhyolitic tuffs, latites, dacites, and andesites; the sediments include brown arkosic quartzite, reddish-brown sandstones and conglomerates. Some conglomerate beds just south of the San

Xavier hills are made up mostly of chert and quartzite pebbles; others farther south are made up mostly of very coarse crystals of quartz and feldspars with andesitic pebbles from one to two inches in diameter. Most of the sandstone beds are rather cross-bedded and fairly well cemented. The quartzites are typically arkosic in character and thin-section studies revealed the presence of an appreciable percentage of feldspars. Some brick-red shales and reddish-brown sandstones are included in the series.

Andesite flows are the predominant volcanic rocks. These are porphyritic with feldspar phenocrysts in a dark-green to purplish groundmass. Epidotization is apparent in most of the flows.

**Recreation Red Beds**

On the east side of the Helmet Peak area is a series of brick-red, green, maroon, and buff colored shales, sandstones and conglomerates. Due to the close similarity of this formation to the Recreation Red Beds of the Tucson Mountains, this name has been adapted for the formation.

Outcrops of similar beds are also present on the northeastern slopes of the San Xavier hills as shown on the geologic map.

The predominance of arkoses and sandstones is rather marked in the formation. Close examination of the rocks
show fairly rounded quartz and feldspar grains cemented by red hematite. The mineral constituents of the rocks suggest the existence of a nearby granite land mass during the time of their deposition. Some facies of the arkosic beds are greenish-gray in color instead of the usual red. This is probably due to the presence of iron silicates.

Some conglomerate beds were observed southeast of the Helmet Peak. They are composed of chert and quartzitic pebbles with fine-grained, iron-rich groundmass. Other conglomerate beds in the formation carry some andesitic pebbles in an arkosic groundmass. The andesite pebbles suggest that the formation was deposited after or contemporaneous with the lava flows.

The base of the formation is buried under the recent alluvium on the northeastern slope of the Helmet Peak. The upper part, southeast of the Helmet Peak, is apparently overlain by a series of coarse-grained, somewhat conglomeratic arkose. The relationship cannot be definitely established due to lack of good exposures.

The Recreation Red Beds in the area are undoubtedly complicated by a series of structures which are not visible on the surface. The presence of some mineralized fissures exposed by open-cuts suggests a more extensive fracturing than is apparent on the surface. Lack of good surface
exposures, both of the beds and the structures, precludes any systematic study of the formation.

No fossils were found in the Red Beds of the area.

White Arkose

A large area of white arkosic rocks with a few limestone beds and green shales is exposed on the middle part of the Helmet Peak area. The arkosic rocks vary from a white fine-grained almost quartzitic variety to a pinkish coarse-grained type that looks very much like a kaolinized or sericitized granite porphyry. In many places the weathered surfaces of the rocks are dark brown to black due to a coating of iron and manganese oxides. Some places show reddish tint which suggests the presence of hematite. The source of iron in the rocks is probably hydrothermal, as shown by the presence of disseminated pyrite, bornite and chalcopyrite in some unoxidized specimens near the Olivette Mine and other open-cuts in the area.

Previous workers and local men have erroneously referred to these rocks as igneous in origin. Some mine reports classified the finer variety as an "altered rhyolite"; others regarded the coarser variety as a "granite rock" or a "porphyry". During the early days of the writer's study, he tentatively mapped the rock as an alaskite, which is a granite low in ferromagnesian minerals. Later studies, however, revealed conclusive evidence that the
rocks are of clastic origin. Distinct bedding planes were found in places. Thin-section examinations revealed the clastic texture of the rock, which is hardly visible in most specimens. Microscopic examination showed the predominance of quartz with fairly abundant feldspars and sericite. The sub-angular shape of the individual grains suggests the clastic origin of the rocks. Some of the quartz grains show interlocking contact similar to quartzite; others are separated by very fine aggregates of sericite and quartz. A more detailed examination of a coarser variety showed the following:

**Megascopic**—Pinkish, coarse-grained rock with sub-angular to angular grains. Pink variety of feldspars are abundant. Without the aid of a hand-lens, the rock looks like a porphyry or a granite.

**Microscopic**—

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>50%</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>20%</td>
</tr>
<tr>
<td>Microperthites</td>
<td>10%</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>10%</td>
</tr>
<tr>
<td>Magnetite, Hematite, Sericite, Chlorite, and other fine-grained minerals</td>
<td>10%</td>
</tr>
</tbody>
</table>

Size of grains varies from 0.05 mm. to 1.5 mm.

Individual mineral grain has angular to sub-angular outline. The grains are interlocked by fine cementing materials, which are composed of quartz, feldspars, sericite and chlorite. Some feldspars are altered to sericite, almost completely. Kaolinization is also apparent in some crystals of feldspars. No intergranular boundaries were seen in this
section that might indicate igneous origin.

The shape of the mineral grains indicates a residual type of deposition. A similar process of deposition is now taking place in the area, where a thick cover of recently deposited materials, derived mostly from the granite, are accumulating on the plains, and in washes and arroyos.

Several beds of green shales and limestones not exceeding ten feet thick are associated with the arkose. The limestone beds are dark gray to bluish gray and somewhat arenaceous. Individual beds rarely exceed two feet in thickness. The fossiliferous beds are characterized by concretionary outlines. Most of the limestone beds drop out in the southern part of section 11 (see Geologic Map), southwest of the Helmet Peak. One of the beds, near the southeastern corner of the Section carries mastroid lamellibranchs. These are Upper Cretaceous fossils characteristic of the Colorado and Montana groups. *Mactra* beds were also reported by W. H. Brown in the Amole Arkose of the Tucson Mountains.

**Correlation of the Cretaceous Series**

The present knowledge of the Upper Cretaceous rocks...
of southeastern Arizona does not justify any precise correlation. A great thickness of this series, about 30,000 feet is known in the Empire Mountains. Wilson\(^1\) reported the presence of Fort Pierre fauna in this section. Feiss\(^2\) reported a series of red shales, fine-grained sandstone, shaly limestone, and conglomerates in the Hiltano Mine, which Brown\(^3\) believes to correspond to the section in the Tucson Mountains.

The Cretaceous of the Helmet Peak area is closely related to the Cretaceous of the Tucson Mountains. The writer visited the Tucson Mountains' section and a striking similarity in the lithology of the Cretaceous section of the areas was noted. It may be safe to conclude that three units of the Cretaceous in the Helmet Peak area correspond to the three units established by Brown in the Tucson Mountains. This conclusion is justified by the proximity of the area to the Tucson Mountains, the presence


of mactroid lamellibranchs in both areas, and the similarity of the red beds in both sections. The mactroid lamellibranchs and fossil plants found in the Tucson Mountains place this series in the Upper Cretaceous.
GEOLOGIC HISTORY

The Archeozoic Pinal schist is the oldest known rock in southeastern Arizona. It is not exposed in the Helmet Peak area but crops out in the Santa Catalina mountains northeast of Tucson and in the Picacho de Calera hills northwest of Tucson.

The earliest Paleozoic event recorded in southeastern Arizona was the invasion of the Cambrian sea over a pre-Cambrian peneplain. The Bolsa quartzite seems to have been formed under near-shore conditions at the start of deposition followed by a change to a deeper sea condition. This is shown by the somewhat gradual change from a conglomeratic base of the formation to finer, almost shaly beds on-top. The sea continued to cover the area and deposited a series of impure limestone. In some districts, the Pima sandstone and the Cochise formation were deposited, but these formations were not recognized in the Helmet Peak area. These were followed by the deposition of the Abrigo formation. The uppermost Cambrian formations known in other ranges (Rincon limestone in the Whetstone mountains, the Copper Queen limestone in Bisbee and Peppersauce Canyon sandstone of the Santa Catalina mountains) of southeastern Arizona were not recognized in the area.
At the close of Cambrian time, the sea withdrew and a great break in the geologic history of southeastern Arizona took place. Except for the Ordovician of Clifton-Morenci and Dos Cabezas districts, no Ordovician and Silurian deposits are known in the entire region. During this time southeastern Arizona was a land area and stood little above sea level.

The sea again encroached on southeastern Arizona during the Upper Devonian and deposited the Martin limestone. The Helmet Peak area received about 250 feet of this limestone. In the Catalina mountains to the north the Lower Ouray limestone was deposited above the Martin limestone. This formation, however, is absent in the area but no time lapse is evident between the Martin limestone and the succeeding Lower Mississippian limestone.

At the beginning of Lower Mississippian time, a deeper sea bringing with it a Kinderhookian fauna developed in southeastern Arizona. A pure, thick-bedded, massive limestone was laid down.

The Upper Mississippian time represents a break in the geologic history of most of southeastern Arizona except in Chiricahua mountains, near the southeastern boundary of the state.

During the Lower Pennsylvanian, a sea encroached upon southeastern Arizona and deposited a series of thin-bedded
to massive limestones and thin-bedded shales. The lower Pennsylvanian deposits in the Bisbee area consist mostly of limestone without any shaly beds. The limestones carry abundant specimens of Fusulina.

The Upper Pennsylvanian is unknown throughout southeastern Arizona.

The Lower Permian sea invaded southeastern Arizona depositing a series of oozes, marly beds and gypsum. This was followed by the deposition of quartzites and bluish gray limestone beds. Near the close of the Permian fossiliferous beds of limestone, known as the Snyder Hill formation were laid down.

After the deposition of the Snyder Hill formation, the sea withdrew and the whole of southeastern Arizona, probably, remained a land area until Cretaceous time. No Jurassic and Triassic deposits are known in the Helmet Peak area and in most of southeastern Arizona. In late Cretaceous time volcanic activities took place. Some evidence of submarine igneous activities is shown by the presence of partly water-laid tuffs in the Tucson Mountains and other areas. Andesite, rhyolite, dacite and latite flows were recognized in the Helmet Peak area. The volcanic activity was interrupted from time to time by deposition of arkoses, sandstone and conglomerates. A series of red shales, arkoses, sandstones and conglomerates were then deposited with very minor volcanic
activity. Before the close of the Cretaceous a thick series of arkosic rocks and some beds of limestones were deposited above the Red Beds.

At the close of Cretaceous time, diastrophic movements took place accompanied by extensive folding, thrust faulting and igneous activity. Paleozoic strata were thrust over the Cretaceous, and possibly some older Cretaceous rocks were thrust over younger Cretaceous. This was followed by normal faulting. During the Early Tertiary (?) a large granite stock was intruded in the area accompanied by dikes and possibly by smaller intrusions. The ore deposits in the Helmet Peak area were probably formed during this time.

During the Late Tertiary (?) another period of igneous activity took place in several areas of southeastern Arizona including the Helmet Peak area.

After these activities, erosion was the dominant process to the present.
IGNEOUS ROCKS

Biotite Granite

The Sierrita mountains consist essentially of an intrusive granite core, which extends to the Helmet Peak area. The granite is flanked by a series of intensely metamorphosed sediments on the west and by slightly metamorphosed Paleozoic and Cretaceous rocks on the east.

On the western slope of the Sierrita mountain, Higdon described the granite as intrusive into the sedimentary series. He mentions off-shoots of dioritic rocks in the limestone beds, presumably from the main granite mass. The limestone shows contact metamorphic minerals with "streaks of tremolite in radial fibrous aggregate associated with galena". Higdon described the granite as a soda granite with abundant microperthite, 15 percent quartz and the conspicuous absence of ferromagnesian minerals, except for sericite, which he thought was alteration of biotite.

In the Helmet Peak area, the granite is apparently intrusive into the Paleozoic and Cretaceous rocks. Evidence of intrusion into the Paleozoic sediments is present.

at the Mineral Hill sub-area where a tongue of granite is in contact with the Bolsa quartzite and the Naco formation. Section E - E' shows the Bolsa quartzite dipping steeply into the granite. This part precludes the possibility of a normal sedimentary contact between the granite and the Bolsa quartzite, but rather suggests an intrusive contact. The intrusive metamorphism in the limestone and the apparent tilting of some of the beds of the Bolsa quartzite lend weight to the intrusive character of the granite. Eckel\textsuperscript{1} mentioned that the granite was encountered at 600 feet by the mine workings in the Mineral Hill sub-area. Ransome\textsuperscript{2} also mentioned this fact and added the possibility that the granite is a sill. A sill would mean the presence of sedimentary rocks below the granite. Eckel, however, believes that the coarse texture of the granite, the intensity of metamorphism of the sedimentary rocks and the large ore deposits associated with the intrusion are indicative of a larger intrusion rather than a sill. He implies that the granite encountered by the mine workings underground is the top of the stock itself and that the presence of sedimentary rocks below

\textsuperscript{1} Eckel, E. B., op. cit., p. 15, 1930.
the present workings is improbable. He added, however, that the question can only be settled by further exploration.

Unlike Ransome and Eckel, the writer was unable to visit the mine workings due to the presence of water and uncertain conditions underground. The writer can not, therefore, express his opinion as to the nature of the intrusive rock underground. He believes, however, that the main granite stock in this area is very close to the surface. The high intensity of contact metamorphism, as shown by the presence of high temperature minerals (garnet, molybdenite, magnetite, etc.) and the proximity of surface outcrops of the main granite stock to the area, support this view.

The mining men of the district informed the writer that the igneous rocks underground are interfingered with the limestone. This relation was not verified, but the presence of granitic and dioritic rocks on the dumps of some of the shafts indicates that granite was encountered.

In the San Xavier sub-area, the evidence for the intrusive nature of the granite is not conclusive. Intensive contact metamorphism of the limestone beds may well be due to the intrusion of the granite. A dike-like body along a fault on the northern side of a hill, east of the Twin Buttes road (see NE quadrant, Section 3), can be traced within a short distance to the main granite body and may
connect with it. It separates a block of Escabrosa limestone from the rest of the limestone.

South of the San Xavier hills, a small body of granitic rock is exposed within the arkose formation (See boundary between Sections 10 and 11) and is apparently a part of the main stock. Some shafts within the White Arkose formation (Section 10) have encountered the granite within a few hundred feet from the surface, as shown by the presence of granitic rocks on the dumps.

The extensive mineralization and the high degree of wall-rock alteration of the volcanic rocks in the south-eastern part of the area are probably due to the granitic intrusion. The contact of the granite and the volcanic rocks, as shown by underground workings, at the Paymaster property, dips to the east. This granite was encountered by a shaft at about 300 feet from the surface. West of the Paymaster property, the contact of the granite with the brecciated andesite is not clear. It is interesting to note, however, that aplite dikes and pegmatitic dikes are abundant near the contact of the granite and the breccia. In general, this type of dikes seems to be near the contact of an intrusive and the intruded rock.

The possibility of the presence of another type of granite (Pre-Cambrian?) within the area has not been overlooked. Numerous differences in color, texture, and
composition of the granite have been observed, but the different types are gradational within the same mass and no separate type of granite was observed.

The granite is a coarse-grained, holocrystalline rock with abundant potash feldspars, albite, quartz and biotite as essential minerals. Some specimens show the marked predominance of potash feldspars and only subordinate sodic feldspars; others show more abundant sodic feldspars, sometimes exceeding the potash feldspars. The latter is almost on the boundary between quartz-monzonite and granite. Similar facies of differentiation within the granite had been reported by Ransome on the eastern slope of the Sierrita mountains, near Magee's Ranch. He described one specimen as chiefly alkali feldspars and quartz with subordinate plagioclase and little biotite. Another specimen he examined from the same general locality showed more abundant plagioclase than the first specimen.

Biotite is the predominant ferro-magnesian mineral in all of the samples examined by Ransome, Eckel, Park and the writer. On the other side of the Sierrita mountains, Higdon observed the conspicuous absence of ferro-magnesian minerals in the granite, but he suggested the possibility of the sericite in the rock as alteration of biotite.

Detailed laboratory examination of a typical specimen taken from the northeast quadrant of Section 10 showed
Megaoscopic: The rock is greenish-white to pinkish-white in color. Large crystals of feldspar and quartz are surrounded by the groundmass. The ferromagnesian mineral is mostly biotite, but it has apparently undergone some alteration. Magnetite and hematite are visible.

Microscopic:

Essential Minerals:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Per Cent</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>15</td>
<td>0.5 to 10 mm.</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>20</td>
<td>0.5 to 10 mm.</td>
</tr>
<tr>
<td>Microperthite</td>
<td>20</td>
<td>0.5 to 8 mm.</td>
</tr>
<tr>
<td>Albite (Ab98An4)</td>
<td>50</td>
<td>0.5 to 10 mm.</td>
</tr>
<tr>
<td>Biotite</td>
<td>10</td>
<td>0.05 to 10 mm.</td>
</tr>
</tbody>
</table>

Accessory Minerals:

- Magnetite = 1%
- Zircon = 1%
- Apatite = -1%

Alteration Minerals:

Sericite, hematite and chlorite.

In thin-section, euhedral to anhedral grains of quartz, feldspar, and biotite predominate. The feldspars have undergone sericitization, either partially or completely. Biotite has undergone partial chloritization. Some pleochroic halos, probably surrounding inclusions of zircon, are included in biotite. Magnetite and apatite occur as small grains scattered through the section.
Granodiorite

The rock is in contact with the granite and a block of limestone on the northern spur of the Esabrosa limestone hill, west of the Twin Buttes road.

**Megascopic:** It is a dark-green to dark-gray rock with abundant quartz, plagioclase, orthoclase, biotite and subordinate epidote, sericite, and apatite.

**Microscopic:**

**Essential Minerals:**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Per Cent</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>40</td>
<td>0.05 to 0.2 mm.</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>10</td>
<td>0.1 to 0.3 mm.</td>
</tr>
<tr>
<td>Andesine (Ab₆₄An₃₆)</td>
<td>20</td>
<td>0.1 to 0.5 mm.</td>
</tr>
<tr>
<td>Biotite</td>
<td>20</td>
<td>0.01 to 0.1 mm.</td>
</tr>
</tbody>
</table>

**Accessory Minerals:**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Per Cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apatite</td>
<td>1</td>
</tr>
<tr>
<td>Epidote</td>
<td>1</td>
</tr>
</tbody>
</table>

**Alteration Minerals:**

Limonite, sericite, and chlorite (?).

A considerable proportion of the area of the section consists of small irregular areas of quartz; much of the quartz was probably introduced by silicification. Some places in the section seem to suggest that the small grains which have been broken by later dynamic movement. The presence of this rock within a fault zone would probably support this suggestion. The biotite in the rock appears to be either a regenerated or introduced mineral.
which occupies the interstitial spaces between the earlier mineral grains. Some sericite are apparently pseudomorphic after biotite, although most of it is a product of the alteration of the feldspars. Direct alteration of the biotite to limonite is also present.

In general, the rock has suffered much metamorphism, but its original character was not completely lost.

Although microscopic and field evidence do not show the definite relation of the granodiorite to the granite, it seems a reasonable assumption that it is a slightly basic differentiate of the granite itself.
DIKE ROCKS

General Statement

Several dikes which are genetically related to the main intrusive granite occur in the area. Due to their small sizes, some were purposely omitted from the geologic map.

The dikes range from the acid type, the aplites and pegmatites, to the very basic variety, the lamprophyres. They vary in width from five to ten feet. Other dikes not exposed at the surface were reported to have been encountered by underground workings.

Aplite and Pegmatite Dikes

Aplite and pegmatite dikes occur mostly within the granite, near the contact with the intruded rocks. Analysis of a typical sample shows that the rock has 50 percent quartz and about 50 percent feldspar (microcline and orthoclase). A very little biotite is the only dark mineral.

The pegmatitic dikes in the Mineral Hill and west of the Paymaster group show graphic texture.

Lamprophyre Dikes

The lamprophyre dikes in the area occur as basic differentiate of the granite. A dike of this type, which is composed essentially of biotite and hornblende
Diorite Dikes

Porphyritic diorite dikes were encountered by mine workings underground as shown by the presence of diorite on the mine dumps. Old mine reports mention the presence of such dikes underground. Small outcrops are also present within the Mineral Hill sub-area.

The rock is composed of hornblende, biotite, a little quartz, and plagioclase feldspars.
VOLCANIC ROCKS

Red Basalts

Red basalts crop out in the southern part of the area. Three main exposures, separated from each other by alluvium, were mapped; but they are apparently parts of a single flow connected under the thin alluvium cover.

The rock is composed of large phenocrysts of plagioclase feldspars (labradorite) in a red, glassy groundmass. The feldspars range in size from one-eighth of an inch to one inch. Gas cavities are very common indicating sub-aereal extrusion of the rock. Some of the gas cavities are either filled or partially filled with calcite thus forming an amygdaloidal texture.

Field evidence seems to indicate that the rocks were extruded along a northeasterly extension of the fault fractures, which are mineralized in the vicinity of the Alpha group property. It is also interesting to note that the alignment of the three outcrops mapped is approximately parallel to the general trend of the fissures in the area.

The age of this formation is Post-Laramide (Late Tertiary?). Its extrusion along fractures in the Late Cretaceous arkose substantiates this contention. It may be as late as Quaternary or Recent.
Andesite Dikes

In the southern part of the area, a series of andesite dikes are intruded into the Cretaceous arkose. The dikes are ten to fifteen feet wide and vary from one hundred to seven hundred feet in length.

Petrographic examination of one sample showed the following:

Megascopic: The rock is light brown with a porphyritic texture. Large phenocrysts of feldspar and dark brown ferromagnesian minerals are visible in a light, grayish-brown groundmass.

Microscopic: The feldspar of the phenocrysts is fresh and shows very little alteration. Albite twinning and combined Carlsbad-Albite twinning are characteristic of the feldspar. Determination of the composition by extinction angles of faces normal to 010 showed that the feldspar is andesine (Ab_{56}An_{44}). Zoning is apparent in some feldspar crystals.

The groundmass consists of very minute crystals of andesine and a light brown glassy material. The size of the phenocrysts ranges from 0.5 mm to 15 mm. maximum diameter.

Undifferentiated Basalts

A series of basaltic rocks occurs in the southeastern part of the area in sections 15 and 16. There are at least three types of basalt in the series, but due to the similarity of their field occurrence and composition, those rocks were mapped as a single unit. They differ from each other only in the color of their groundmass, which depends upon the amount of iron oxide.
Because of the inadequate field evidence, it is impossible to determine whether the basalts are intrusive or extrusive. The longer dimension of the outcrop is roughly aligned with the major structure in the vicinity.

Examination of the maroon-brown variety of basalt showed the following:

**Megascopic:** The rock has euhedral feldspar phenocrysts on a very fine, maroon-brown groundmass. The feldspars are pinkish white to brownish in color.

**Microscopic:** Thin-section examination of the rock showed a very fine groundmass, which consists of minute euhedral crystals of feldspar and a glassy material. The small crystals of feldspar in the groundmass show a more or less definite orientation along one direction. The glassy groundmass shows a flow structure along a similar direction.

The feldspar phenocrysts are highly altered and sericitized. Determination by the extinction angle method of sections normal to O10 shows that the feldspar is labradorite. Other phenocrysts with the outlines of olivine are almost completely altered to a brownish-pink mineral (iddingsite?). Secondary magnetite forms as border rims of olivine crystals. Limonite, hematite, and secondary carbonates are also present in the section.

Examination of the gray variety of basalt showed the following:

**Megascopic:** Rock has visible white feldspar phenocrysts in a brownish-gray groundmass.
Microscopic: The phenocrysts are mostly plagioclase feldspar, hornblende, and olivine. Their approximate size and proportion in the section are as follows:

- Labradorite (Ab$_{46}$An$_{54}$) = 0.05 to 1.0 mm. = 15%
- Olivine = 0.01 to 0.5 mm. = 10%
- Hornblende = 0.01 to 0.3 mm. = 3%

The feldspar crystals are sericitized but the twinning is still distinct in most of them. The olivine crystals show alteration to secondary magnetite around the rims. The groundmass consists of minute crystals of feldspar and a glassy material which shows a typical flow structure. Secondary carbonates are present.

Green Andesite

A green andesite has a relatively wide areal distribution. The main mass occurs on the northern part of section 15 and extends to the southern part of section 10. Within the same mass the rock shows variation in texture which ranges from a decidedly porphyritic type to a fine-grained almost non-porphyritic variety.

Dike-like bodies of this rock occur within the Cretaceous series of the area. Small patches are also distributed in many places on the southern part of the area. The nature of these patches is not clear, but they seem to represent small necks or plugs which have reached the surface through some weak zones in earlier rocks.
The main mass has the character of a near-surface intrusive, which occupies a broad fault zone. Thin-sections of two representative varieties of the green andesite were examined. The porphyritic variety showed a high degree of hydrothermal alteration. Most of the phenocrysts are highly sericitized andesine. Some grains, however, still show the ghosts of albite twinnings and crystal outlines. Chlorite is abundant as the alteration product of ferromagnesian minerals. The groundmass is very fine-grained and almost glassy with small euhedral feldspar laths. Hematite is abundant, probably as the latest stage of alteration of the iron-bearing silicates.

The fine-grained variety is similar in composition to the porphyritic variety. The thin-section shows minute crystals of euhedral andesine feldspars and the abundance of chlorite.

Since the rock intrudes the upper members of the Cretaceous series in the area, its age is very late Cretaceous or post-Cretaceous. Mineralization within the formation is rather extensive and the writer believes that it is related to the Laramide granite intrusion.
Gray Andesite

At the Paymaster property on the southwestern part of the area, a gray variety of andesite is in contact with the andesitic breccia (see page 70) and the Mill andesite. The nature of its occurrence is not clear, but the absence of flow structure and other criteria for sub-aereal deposition indicates that the rock is a shallow-depth intrusive.

The rock has a porphyritic texture with feldspar phenocrysts from one to four millimeters in diameter. Microscopic examination shows the presence of red iron oxide and a very high degree of hydrothermal alteration. Most of the feldspars were completely altered to sericite and kaolin, but the original crystallographic outline and albite twinning are still visible in some grains. Large crystals of red hematite, pseudomorphic after hornblende, are abundant in the section. Their size ranges from 0.02 to 0.5 millimeter. The gray-colored groundmass consists of very fine-grained crystals of feldspar and quartz. The quartz was probably introduced into the rock during later metamorphism.

The rock as a whole is greatly altered and has undergone a large amount of shearing and brecciation. Parts of the Paymaster veins are mineralizations along fractures within this formation.
Mill Andesite

A dark bluish-gray type of andesite occurs in contact with the Gray andesite and the andesitic breccia within the Paymaster group. The nature of its occurrence is very similar to the gray andesite.

The name Mill andesite is suggested by the writer for this formation, because of the presence of the old mill which was operated by the Olberg Exploration Co. of California in 1940, within the area of the formation.

The rock is porphyritic in texture with visible feldspar phenocrysts. A blue mineral is present in the rock, but it is difficult to identify without the aid of a petrographic microscope. The groundmass is dark-brown to dark-gray with shades of green. Hematite and magnetite are visible megascopically.

In thin-section, the rock shows a very intensive degree of hydrothermal alteration. The feldspars, which constitute about 20 percent of the rock, are the most predominant phenocrysts. They are almost completely sericitized and kaolinized. Serpentine constitutes about 30 percent of the section and is probably an alteration product of the ferromagnesian minerals. Secondary magnetite and hematite are also abundant as alteration products of iron-bearing silicates. Secondary carbonates are present in the section, some of which suggest pseudomorph-
ism after a mineral which looks very much like an olivine. The groundmass is fine-grained, but not glassy in texture. With the aid of a high power objective, the groundmass appears to be composed essentially of quartz and feldspar. The quartz was evidently introduced into the rock by hydrothermal solutions. No phenocrysts of quartz were observed.
STRUCTURAL GEOLOGY

General Statement

In order to present a comprehensive picture of the structures in the area, a brief description of the regional structure of the surrounding districts will be given with a view of determining the relation of the broad features of the region to the local structures. This description will be followed by a general discussion of the structures in the Helmet Peak area, such as folding, thrust faulting and steep-angle faulting, comparing these features with those of the surrounding region whenever possible. The area will then be divided into four sub-areas and a detailed description of each of the sub-areas will be discussed. Structural features which have definite relation to the ore deposits will be emphasized.

Due to the lack of good surface exposures in some places in the area, it is rarely possible to obtain all the desired data upon which conclusive interpretation can be based. In this discussion, therefore, the writer will try to differentiate the observed facts from postulations which are based either upon inconclusive evidence or plain hypothesis.
Regional Structure

From the close of the Cretaceous to the early Tertiary, a great period of folding and faulting followed by igneous intrusion took place in southeastern Arizona. Thrusting of Paleozoic strata over younger beds has been described in several areas.

The present ranges of southeastern Arizona are generally regarded as a part of the great Basin and Range province which consists essentially of fault blocks, most of which were tilted. A very interesting discussion of the Basin and Range type of structures in the Tucson Mountains, only twenty miles north of the Helmet Peak area, has been given by Dr. W. H. Brown. He described the three distinct structural periods as follows:

1. The older rocks forming a pre-Laramide block of folded, thrust-faulted and intruded sedimentary and volcanic rocks which were eroded to a surface approaching a peneplain.

2. This block was then buried beneath a thick series of Tertiary volcanic rocks which were tilted more or less uniformly toward the east, intensely faulted by at least two groups of normal faults and eroded to a rugged surface.

3. The resulting surface was then covered by a series of basaltic flows mostly flat lying.

but locally disturbed.

Brown has shown the presence of thrust faulting in the Tucson Mountains followed by steep-angle faulting and tilting of blocks forming the present structures of the mountains.

Workers in the Santa Rita and the Empire Mountains have recognized thrust faulting in those areas. Evidence shows that thrusting is generally earlier than the main intrusive bodies and are usually followed by steep-angle faults. Schrader\(^1\) postulated the overthrust structure in the Santa Rita mountains and this was later verified by Thomas\(^2\) in the Rosemont area (Santa Rita Mountains).

Wilson\(^3\), who studied the structures of the Empire Mountains, postulated an overthrust in the Empire mountains. Gillingham\(^4\) observed that the Permian Snyder Hill limestone is thrust upon the Cretaceous, with the thrust plane dipping gently to the east and the strike about north-south.


2. Thomas, W. L., Geol. and Ore Deposits of the Rosemont Area, Pima County, Arizona, Unpublished Manuscript, Univ. of Arizona, 1931.


Galbraith, in an abstract published by the Geological Society of America, summarized the general structure of the Empire Mountains as follows:

"The Empire Mountains are believed to be characterized by an overthrust of considerable magnitude. The range is separated into two structural units, the basement block, consisting of Upper Cretaceous sandstones and shales, folded into broad anticlines and synclines with east-west axes; and the overthrust block, made up of 3000-6000 feet of Paleozoic rocks dipping about 45 degrees to the eastward and unconformably overlain by Upper Cretaceous shales with a similar attitude."

Galbraith concluded that: "The Empire Mountains appear to be an admirable example of a typical Basin and Range which has been formed by overthrusting rather than tilting along a high-angle fault. Large scale overthrusting is known to exist in several neighboring ranges, and recent studies tend to accentuate rather than minimize the importance of the thrust faulting."

From the foregoing discussion of the structures in the Tucson Mountains, Santa Rita Mountains, and the Empire Mountains, it is quite evident that thrust faulting is a major structural feature of the region surrounding the Helmet Peak area.

Folding of sedimentary rocks was recognized in the Escabrosa limestone of the San Xavier sub-area. Although only few strikes and dips are obtainable in

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the Cretaceous strata, their variation suggests that
the Cretaceous beds were folded.

In general, there are two systems of fracturing
in the area: (a) northwest-southeast system (b)
northeast-southwest system. The northeast trend­
ing fracture system is of greater economic importance,
although some of the northwest trending fractures are also
ore-bearing.

The presence of a wide zone of brecciated rocks with
low-angle or horizontal fault planes associated with
them suggests thrust-faulting in the area. The breccia
zone covers about 2½ square miles in the southeastern part
of the area. This zone probably represents the thrust­
fault zone from which the overlying plate has been
largely removed by erosion.

Blocks of Paleozoic quartzite and limestone,
apparently resting on the Cretaceous strata, are also
possible evidence of thrusting.

LOCAL STRUCTURES

General Statement

To present a systematic discussion of the struc­
tures, the area will be divided into four sub-areas, as
follows:

1. Mineral Hill sub-area
2. San Xavier sub-area

3. Helmet Peak sub-area

4. Olive-Camp sub-area (includes the entire area south of the San Xavier sub-area extending to the southern limit of the area).

MINERAL HILL SUB-AREA

Features

The sedimentary rocks in the Mineral Hill sub-area form a monoclinical structure with an average strike of N 60° W and dip 50 degrees to the southwest. Variations in the attitude of the rocks, both horizontal and vertical, were observed but they are of local nature. Faulting and intrusion of igneous rocks have changed the local dips of the beds from 50 degrees to almost vertical, but no marked change in the strike was observed.

An east-west section across the sub-area (Section E-E' plate II) shows older beds resting on younger beds. This feature suggests an overturned fold.

The principal structure in the sub-area is a fault of considerable magnitude which brings the Pennsylvanian Naco formation in contact with the Cambrian Bolsa quartzite and Abrigo formation. Due to the extensive mineralization along this fault, it will be referred to as the
Mineral fault. It was traced from the arroyo near the Plumed Knight shafts (northeast corner of Section 2) and west-northwestward to the saddle between the two hills just north of the Mineral Hill Consolidated shaft; from this saddle the fault trends in a westerly direction until it is cut off by the granite intrusive on the western slope of the hill near the road. It is a normal fault with the south side, (Pennsylvanian Naco formation), relatively dropped down against the north side (Cambrian Bolsa quartzite and Abrigo limestone). The average dip of the fault is 55 degrees.

Three cross-faults of lesser magnitude were mapped on the north side of the Mineral fault striking about N 45° E to N 50° E with an approximately vertical dip. Displacements along these faults vary from a few feet to about one hundred feet vertically. Drag folding close to the fault zone is apparent, indicating horizontal movement.

The contact of the Escabrosa limestone and the Naco formation in the western part of the sub-area is a fault contact striking about N 40° E with a vertical dip. Mineralized fractures striking about N 40° E are present within the Abrigo formation. Other mineralized fractures were mapped on the western slope of the westernmost hill in the sub-area, striking about north-northwest to northwest. Some north-south fractures control most of the mineralization within the limestone outside the
contact zone. These are poorly exposed on the surface but are clearly outlined underground.

Interpretations:

The presence of older on younger beds suggests that the entire sub-area is the lower limb of an overturned fold, the axis of which dips to the southwest; the upper limb having been eroded or obliterated by the intrusive stock. Figure 1 shows the general relations.

Another possible explanation is that a monoclinal block dipping to the northeast was tilted to its present southwest dip by the intrusion of the stock.

The first interpretation seem the more logical.

Northwest of the Mineral Hill sub-area, a group of Paleozoic limestone blocks are apparently resting on the granite. The exact nature of these blocks is not clear, but some contact metamorphism in the limestone suggests that the granite is intrusive into the limestones. The blocks appear to be erosional remnants of much larger bodies of sedimentary rocks possibly thrust over a pre-granite fault plane. Probably the thrust plane was considerably below the present surface and was occupied by the granite intrusion. These limestone blocks are similar to the Klippen described by Brown in the Tucson Mountains.
Diagrammatic Section Showing Structure in the Mineral Hill Sub-area

Figure 2.
Similar type of blocks of limestones are present in the Vulcan property and the same explanation probably holds true.

HELMET PEAK SUB-AREA

The beds in the Helmet Peak have an approximately vertical dip and strike about N 20° W. Crenulations or tiny folds were observed along the strike.

Helmet Peak is bounded on both sides by steep angle faults that strike approximately parallel to the beds. These faults bring the Permian Snyder Hill limestone in contact with Cretaceous beds on both sides of the peak. On the western slope, the fault strikes N 15° W and dips about 85 degrees to the southwest. The fault on the eastern slope strikes about N 25° W and dips 70 degrees to the northeast.

Blocks of Snyder Hill limestone surrounded by the Cretaceous strata are present southeast of the Helmet Peak. Two of the blocks are flanked by conglomerate beds suggesting sedimentary contact.

Interpretation

Two interpretations of the structure in the Helmet Peak are suggested from the inconclusive evidence:

1. That the entire Permian limestone block is a part of a larger Paleozoic block thrust over the Cretaceous strata and
3. That the Permian limestone block was elevated between the two faults forming a "horst-type" of structure.

The small blocks of limestone southeast of the Helmet Peak are similar to the blocks of limestone which Brown described in the Tucson Mountains. One possibility suggested by Brown in explaining these blocks is that "the limestone blocks are remnants of a great sheet which has been practically entirely removed by erosion, leaving numerous klippen on the thrust".

Inasmuch as thrusting is known in the region this explanation deserves consideration.

SAN XAVIER SUB-AREA

The sedimentary rocks east of the main road have a general east-west strike and dip 25 degrees to 45 degrees to the south. The Permian strata west of the road have a similar strike but slightly steeper dip. The Escabrosa limestone to the west of the road has a variable dip and strike and apparently has undergone some folding (see section A - A', plate II).

The principal structure in the sub-area is an east-
west fault that brings the Cretaceous strata against the Paleozoic beds. The fault outlines the southern foot of the hills on both sides of the main road. The fault dips about 60 degrees to the south with the Paleozoic sedimentary beds on the north side dipping toward the fault at 45 degrees. The Permian rocks east of the road are faulted against the Cretaceous volcanic series, whereas those west of the road are faulted against the white arkose. The eastern extension of the fault is buried under detrital material, but it apparently separates (structurally) the Helmet Peak and San Xavier sub-areas. West of the road, the fault is offset by a northeast trending fault that pushed the western extension slightly southward.

A northeast fault west of the highway brought the Permian Manzano quartzite against the Escabrosa limestone. This represents at least 1000 feet vertical displacement. The fault strikes about N 80° E and, although the dip is not clear, it is probably steep. The eastern extension of the fault is buried under alluvium, but it apparently is terminated by the same northeast fault that off-set the major east-west fault.

The northern contact of the Escabrosa limestone with the granite and with the Naco formation, west of the road, is apparently a fault contact which has a N 55° W strike. The dip is almost vertical.

The contact of the limestone and the granite on
the western side of the hill is a low-angle fault plane
dipping about 20 degrees to the east. The strike is
slightly to the northwest. The fault is exposed by an
incline following the fault plane. The granite rock in
the vicinity of the contact appears to be badly crushed.

Other fractures in the sub-area were mapped, but
their dips are difficult to determine. Their strikes
vary from north-south to east-west, but there is a
predominance of the N 45°-60° W and N 60°-70° E
fractures. A brief underground examination of the
fractures in the mine of the Empire Zinc Company showed
the predominance of these systems.

An interesting, but puzzling, feature in the sub-
area is the presence of Cretaceous rocks in a depression
on the northern slope of the San Xavier hill. The rocks
are Cretaceous sedimentary and fine-grained tuffaceous
rhyolite surrounded by the Permian limestone strata.

Interpretation: The Cretaceous rocks were probably laid
down on a deep erosional surface of the Permian lime-
stone beds, and have possibly been lowered somewhat along
a northwest fault.
OLIVE CAMP SUB-AREA

Due to the poor surface outcrops of the Cretaceous strata in the sub-area, the definite pattern of folding could not be completely mapped. That folding is present is shown by the variation of the scattered dips and strikes obtainable in the sub-area.

The Olive Camp sub-area is traversed by three general fracture systems:

1. N 20°-50° E
2. N 65°-85° E
3. N 10°-20° W

Systems 1 and 2 are of greater economic importance, although some of 3 are mineralized. Breccia rocks present in almost every fracture indicate some movement. The fractures vary from six inches to three feet in width.

The N 20-50° E fractures are predominant in sections 16 and 15 of the sub-area, but northward they join the N 65°-85° E system. There are many fractures and only those which have undergone considerable prospecting are shown on the map.

Structural Breccia

A wide zone of breccia rocks occurs in the southern part of the Olive Camp sub-area. The breccia rocks are
divided into two types: (1) Andesitic breccia (2) Quartzitic breccia.

The andesitic type is composed largely of angular fragments of light gray to purplish-gray rocks varying from fine materials to two inches in size. In places, the formation shows a brecciated gray andesitic rock; in other places, it contains large angular quartzitic fragments cemented by a dark brown ferruginous groundmass.

The andesitic breccia is in contact with the green andesite in the northwestern part of section 15. It extends southwestward to section 16, at the Paymaster property. The formation is buried under the alluvium south of the Paymaster property, but isolated outcrops were mapped farther south in section 21.

The hills at the Alpha group are composed of extensively brecciated Cretaceous arkosic quartzite. Similar rocks are found farther south in sections 21 and 22. In section 21, the rocks are badly shattered and numerous fault planes were observed, some of which dip rather steeply, whereas others are nearly horizontal. Angular fragments of volcanic rocks are also associated with the quartzite. These fragments must have been dragged from a far source as similar type of rocks is unknown in the immediate vicinity.

Brecciated quartzite is also present on a hill in section 10 and on another hill at the boundary of
sections 10 and 15. On these hills the angular fragments of quartzite are cemented by a dark brown ferruginous material.

The Breccia Hill in the western part of section 15 is a jumble of angular fragments of rocks. The angular materials vary from very fine fragments to six-inch blocks. Most of them are arkosic quartzite similar to those described previously, but some fragments of volcanic rocks are also present. The hill is traversed by fractures which are silicified and mineralized with oxides of iron. Slickensides dipping and striking in different directions are abundant. The two most prominent fault planes in the hill dip slightly to the east. The fault plane on the top of the hill is almost horizontal and the slickensides show an approximately east-west movement.

In the southeastern part of the area, a narrow strip of brecciated Paleozoic quartzite and limestone is flanked on both sides by Cretaceous arkose. In one place a narrow strip of Paleozoic rock, only ten feet wide, is bounded by the Cretaceous arkose on both sides and there seem to be good indications that the arkose extends below and under the limestone strip.

In sections 10 and 11, blocks of Manzano quartzite rest on the Cretaceous arkose. Like the Paleozoic lime-
stone blocks in the area, these quartzite blocks are apparently klippen on the Cretaceous strata.

Interpretation:

The breccia zone of Cretaceous arkose and andesitic rocks probably represents the thrust fault zone from which the overlying block has been largely removed by erosion.


METAMORPHISM

General Statement

Metamorphism in the Helmet Peak area of the contact type includes recrystallization of limestones to marble, silicification and silication of limestones and shales, bleaching of quartzites to some extent, and development of hornfels. Metamorphism has been caused by pneumato-lytic action, presumably of emanations of water or water vapor and other gases which carried silica and iron from intrusions into the surrounding rocks. Impure limestone beds are altered to quartz, silicates and residual carbonates.

The purer limestones show extensive marbleization. Impure limestone shows more development of complex silicates and little marbleization.

Metamorphism of Limestone

In the Mineral Hill property, the impure Abrigo and Naco formations show a wide zone of silicates. Abundant garnet and epidote with subordinate amphiboles, pyroxenes, and wollastonite characterize the metamorphosed areas. Wide zones of shattered rock have been altered to nearly solid garnet (andradite). The predominance of this mineral and the almost complete absence of amphiboles and pyroxenes indicate a relatively high
temperature of metamorphism and close proximity of the main intrusive mass.

Silicates are abundant in the Permian limestones of the San Xavier sub-area. Near the No. 6 shaft of the Empire Zinc Company (west of the Twin Buttes Road) a dark brown hill composed of garnet takes the place of what was once a part of the Manzano limestone. Shear zones and fault fractures near this area are marked by the presence of garnet and iron oxides. Underground workings, below the No. 2 and No. 5 shafts of the Empire Zinc Company; (east of the Twin Buttes road), show abundant hedenbergite associated with galena and sphalerite together with a little garnet.

The pure Escabrosa limestone is marbleized rather than silicated. Epidote and other silicates are confined to a few open fissures in the limestone.

Metamorphism of Shales

The shales of the Naco formation have been quite extensively affected by metamorphism. Hard, tough, and dense chert-like rocks (hornfels) have resulted. The weathered surface of the metamorphosed shales shows a brown irregularly pitted surface. Alternating bands of grayish-green and white layers characterize some beds. The metamorphosed shales, as a whole, are vary resistant to weathering and erosion; therefore they stand as
ridges and escarpments in the area. The original nature of the metamorphosed shales is revealed by the shaly beddings well preserved in many outcrops. There are some porcelain-like siliceous hornstones which resemble novaculite.

Thin-section examination of some samples showed typical mosaic textures. Minerals include biotite, muscovite, quartz, hematite, and small amounts of garnet and epidote.
**MINERALOGY**

The following is a list of observed minerals in the Helmet Peak area:

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<th>Iron Minerals</th>
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<td>Chalcocite</td>
<td>Hematite</td>
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<td>Chalcopyrite</td>
<td>Limonite</td>
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<td>Plumbojarosite</td>
<td>Labradorite</td>
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<td></td>
<td>Gypsum</td>
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</tbody>
</table>
Copper Minerals

**Bornite Cu₅FeS₄, 55.5% Cu**

Hypogene bornite is present in the Helmet Peak mine, the Swastika mine, the Olivette, and other mines. Bornite replaces pyrite and is contemporaneous with chalcopyrite in ores of the Helmet Peak and Swastika mines.

**Chalcocite Cu₂S, 79.8% Cu**

Chalcocite was recognized in hand specimens and in polished sections of the ores from the Mineral Hill sub-area. It is definitely a supergene mineral derived from the secondary alteration of chalcopyrite along gangue boundaries. Veinlets of chalcocite traverse the cracks in the sphalerite. Chalcocite coatings on the pyrite crystals were observed in some specimens.

In the Helmet Peak and Swastika mines, chalcocite is apparently due to supergene replacement of bornite and chalcopyrite.

**Chalcopyrite CuFeS₂, 34.5% Cu**

Chalcopyrite is the principal ore of copper in the Mineral Hill sub-area. It is also the main source of copper in the San Xavier and the Olive Camp, although it is subordinate to sphalerite and galena.

Its typical occurrence is either as mass replacement in the limestone or as veinlets in the earlier minerals.

Polished section studies of the ores from the
Mineral Hill and San Xavier mines show that chalcopyrite occurs as blebs in sphalerite, and definitely earlier than galena. It is intimately associated with magnetite pseudomorphs as later filling along the original hematite plate boundaries and along cracks traversing the plates.

In the Helmet Peak mine it occurs as a primary mineral contemporaneous with bornite and earlier than galena. Chalcopyrite, with bornite, replaces early pyrite along fractures.

**Covellite CuS, 66.5% Cu**

Covellite is rare in the ores of the area and its presence was observed only in the polished sections. It occurs as supergene veinlets in the chalcopyrite of the Mineral Hill sub-area and in the chalcopyrite and bornite of the Helmet Peak and Swastika mines.

**Tennantite 5Cu_2S_2(Fe,S)S_2As_2S_3, 51.5% Cu**

Tennantite is present in the Helmet Peak mine later than sphalerite and apparently later or contemporaneous with bornite and chalcopyrite.

**Tetrahedrite 5Cu_2S_2(Fe,S)Sb_2S_3, 45.6% Cu**

Tetrahedrite is present in the Mineral Hill sub-area associated with the other sulphides. It was also reported to be present in the Helmet Peak mine.
Azurite $2\text{CuCO}_3\cdot\text{Cu(OH)}_2$, 55.1% Cu

This azure blue carbonate is present in small quantity in the Mineral Hill and San Xavier sub-areas associated with malachite.

Malachite $\text{CuCO}_3\cdot\text{Cu(OH)}_2$, 55.1% Cu

Malachite is common throughout the area as an oxidation product of the copper sulphides.

Chrysocolla $\text{CuSiO}_3\cdot2\text{H}_2\text{O}$, 36.0% Cu

Chrysocolla is associated with malachite as oxidation product of the copper minerals.

Zinc Minerals

Sphalerite $\text{ZnS}$, 67% Zn

Sphalerite occurs as replacement in limestone and as fillings in narrow fissures and breccia zones. It is one of the earliest sulphides to be deposited. Microchemical analysis of the sphalerite from the San Xavier show the presence of iron.

A small amount of sphalerite is present in the Mineral Hill sub-area.

Aurichalcite $2(\text{Zn,Cu})\text{CO}_3\cdot3(\text{Zn,Cu})(\text{OH})_2$

Park$^1$ reported the presence of this mineral at the San Xavier subarea as a fissure filling in the garnetized limestone.

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1. Park, C. F., Jr. op. cit. p. 20.
Hemimorphite $2\text{ZnO} \cdot \text{SiO}_2, 54.2\% \text{Zn}$

Calamine is present in the oxidized zones of the sphalerite-bearing deposits. It is associated with smithsonite.

Smithsonite $\text{ZnCO}_3, 52.1\% \text{Zn}$

Smithsonite is fairly common at the San Xavier mines within the oxidized zone. It is also present in most of the mines in the Olive Camp.

Lead Minerals

Galena $\text{PbS}, 86.6\% \text{Pb}$

Galena is the most important ore of lead in the area. Together with sphalerite, galena occurs as meta-somatic replacement in the San Xavier mine and as fissure fillings in narrow veins of the Olive Camp.

The galena at the Olive Camp sub-area is highly argentiferous and thousands of tons have been mined for the silver content.

The galena observed in the polished sections ores from the San Xavier and the Helmet Peak mines shows that it is one of the latest hypogene sulphides.

Anglesite $\text{PbSO}_4, 68.3\% \text{Pb}$

Anglesite is associated with cerussite in the oxidized zones of the galena-bearing deposits of the area.

Cerussite $\text{PbCO}_3, 77.5\% \text{Pb}$

Cerussite is common in the oxidized zone of the
San Xavier and Olive Camp ore deposits.

Plumbojarosite Pb₀₃Fe₂0₃·4SiO₃·6H₂0, 19.7%Pb

Plumbojarosite occurs with limonite in the material on some of the dumps in the area.

Iron Minerals

Jarosite K₂Fe₆(OH)₁₂(SO₄)₄

Jarosite is fairly common in the oxidized zones of the area. It is associated with limonite, but it can be differentiated from the latter by its yellowish color, pearly lustre, and micaceous texture.

Limonite Mixture of hydrated iron oxides

Limonite is a common product of oxidation of the iron minerals. It is a widespread and well-known mineral in the area.

Hematite Fe₂0₃

Hematite is present in the Mineral Hill and San Xavier deposits. Examination of polished-sections show that it is almost completely replaced by magnetite, although its original crystallographic character is preserved. Blebs of hematite in the magnetite are observed under the polarized light.

Magnetite Fe₀·Fe₂0₃

Two types of magnetite are observed in the Mineral Hill-San Xavier area. One type is laminated magnetite which inherited the original crystallographic character of hematite and the other type is primary magnetite which is
not pseudomorphous after hematite.

**Pyrite** FeS$_2$

Pyrite is the most common sulphide in the Helmet Peak area. It is not only in the fissures but also disseminated in the country rocks. Pyrite is commonly associated with copper minerals which replace it forming typical bomb structure. It is one of the earliest sulphides in the ore deposits of the area.

**Siderite** FeCO$_3$

Siderite occurs in the San Xavier and Mineral Hill sub-areas as fissure fillings in the limestone.

**Molybdenum Mineral**

**Molybdenite** MoS$_2$

Molybdenite is present in the Mineral Hill sub-area. It is associated with chalcopyrite. There were only two specimens where molybdenite was recognized. Neither section shows definitely the age relation of molybdenite with the chalcopyrite.

**Manganese Mineral**

**Pyrolusite** hydrous manganese oxide

This mineral occurs as black crusts and dendrites on the surface of the arkose and quartzite rocks in the area.
Gangue and Non-Metallic Minerals

**Albite NaAlSi3O8**

Albite occurs as a constituent of the granite stock.

**Andesine** Silicate of Al, Na, and Ca

Andesine occurs in the andesite and diorite rocks in the area.

**Apatite (CaF) C4 (PO4)3**

Apatite is abundant as an accessory mineral in the igneous rocks of the area.

**Aragonite CaCO3**

This mineral is fairly common as fissure fillings in the limestone areas.

**Biotite (H,K2)(Mg,Fe)4(Al,Fe)2(SiO4)4**

Biotite is the principal ferromagnesian mineral of the granite. It is also present in the volcanic rocks and other igneous rocks in the area.

**Calcite CaCO3**

Calcite makes up most of the limestone. It is also present as a secondary mineral in some of the ore deposits in the area.

**Chlorite 5MgO·Al2O3·3SiO2·4H2O**

Chlorite is present as alteration product of the ferromagnesian minerals in the igneous rocks.

**Dolomite (Ca,Mg) CO3**

Dolomite occurs as a constituent of some limestone beds, but only in a very limited amount. It also occurs as
a common fissure fillings.  

**Epidote** $4\text{CaO} \cdot 3(\text{Al},\text{Fe}_3)_2 \cdot 6 \text{SiO}_2 \cdot \text{H}_2\text{O}$

Epidote is abundant in the metamorphosed zones in the limestone. Epidotization is common in the Cretaceous volcanic rocks in the area.

**Garnet** $3\text{CaO} \cdot \text{Fe}_2\text{O}_3 \cdot \text{SiO}_2$

Garnet is very abundant in the Mineral Hill sub-area. It is produced by contact metamorphism of the limestone. Solid masses of garnet are also present in the San Xavier sub-area. Examination of some specimens of garnet shows that they are mostly the iron garnet, andradite.

**Gypsum** $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

Gypsum occurs as a sedimentary deposit associated with marls, shales and limestones.

**Hedenbergite** $\text{CaFe(SiO}_3)_2$

Hedenbergite is present in the San Xavier mines as a contact metamorphic silicate. It is associated with galena and sphalerite ore. The temperature of formation of hedenbergite is regarded to be lower than that of garnet.

**Hornblende** $\text{Ca,Mg,Fe(SiO}_3)_2 \cdot \text{NaAl(SiO}_3)$

Hornblende is a common mineral in the igneous rocks.
Kaolin $\text{H}_4\text{Al}_2\text{Si}_2\text{O}_9$

Kaolin occurs in the igneous rocks as alteration product of the feldspars.

Labradorite (Lime-soda Feldspar) $\text{Ab}_{50}\text{An}_{50}-\text{Ab}_{50}\text{An}_{70}$

Labradorite is an essential mineral in the basic igneous rocks.

Microcline $\text{KAlSi}_3\text{O}_8$

Microcline is present in the granite stock.

Olivine $(\text{Mg,Fe})_2\text{Si}_0\text{O}_4$

Olivine is present in the basaltic rocks in the southern part of the area.

Orthoclase $\text{KAlSi}_3\text{O}_8$

Orthoclase is present as an essential mineral in the granite stock.

Quartz $\text{Si}_0\text{2}$

Quartz is the most important gangue mineral. There seem to be more than one generation of quartz in the ore deposits. One generation appears to be earlier than the sulphides, while another is distinctly later.

Quartz is also an essential constituent of the granite stock and other acidic igneous rocks.

Tremolite $\text{CaMg}_3(\text{Si}_0\text{3})$

A few specimens were reported by Eckel in the Mineral Hill sub-area.
Wollastonite $\text{CaO} \cdot \text{SiO}_2$

This is a rather abundant metamorphic mineral in the limestone area close to the contact with the igneous rocks.

It is produced by the introduction of silica to the zone of metamorphism. The reaction is as follows:

\[
\text{CaCO}_3 + \text{Heat} \rightarrow \text{CaO} + \text{CO}_2
\]

\[
\text{CaO} + \text{SiO}_2 \rightarrow \text{CaO} \cdot \text{SiO}_2
\]

(Wollastonite)

Zircon $\text{ZrSiO}_4$

Zircon was observed in a thin-section of the granite stock.
General Statement

The ore deposits in the Helmet Peak area are located in the northwestern part of a belt of mineralization, known as the Pima Mining District, which is about three miles wide and eight miles long along a northwest-south-east trend. This belt extends from the Twin Buttes mining camp, on the southeast, to the Mineral Hill mining camp, on the northwest, and is controlled mainly by the contact between the intrusive granite and the Paleozoic and Mesozoic sediments.

The four mining camps in the district are the following:

1. Twin Buttes camp, principally a copper producer with subordinate gold, silver, lead and zinc. Recently some tungsten has been found.

2. Olive camp, principally a silver, lead, zinc producer with some gold and copper.

3. San Xavier camp, principally a lead-zinc producer.


The last three camps mentioned lie within the Helmet Peak area.
The ore deposits in the Helmet Peak area are discussed under three types based on the principal metal or metals produced.

1. Copper deposits (Contact Metamorphic)

2. Complex lead-zinc-silver deposits
   (a) as metasomatic replacements in limestone
   (b) In fissure veins and breccia zones

3. Gold-pyrite deposits

The copper deposits have been formed in the Paleozoic limestone along intrusive granite contacts. Included in this type are the deposits of the Mineral Hill Consolidated Copper Company, of the Vulcan group, and of the Gray Copper mine. The ores in these mines are associated with strong garnet mineralization. Chalcopyrite constitutes the most important copper mineral.

The complex lead-zinc-silver ores are subdivided into two classes. Ores of the first class are replacements in limestone closely related in origin to the intrusion of the granite exposed in the western part of the area. The complex sulphide ore deposits of the San Xavier mine of the Empire Zinc Company belong here. Some copper minerals are also present in these deposits.

Most of the ores of the second class are deposits along narrow fissures in the arkosic sediments and volcanic
rocks of the Olive Camp sub-area. The ore bodies of the 
Olivette Mine, of the Swastika Mine and Milling Company, 
of the Paymaster Silver Company and of the Vivienne 
Mining Company belong to this type. The ore deposits of 
the Helmet Peak Mining Company occur in an area of brec-
ciated volcanic rock.

The gold-pyrite ores occur as narrow vein deposits 
in the southern part of the area. Veins of this type 
are relatively few and information as to the amount of 
production and other features of the deposits is not 
available to the writer. Some veins in the Alpha group 
belong to this type.

The ore deposition at the San Xavier and the Olive 
camp sub-areas is related to the northeast trending 
fractures. In the San Xavier sub-area, the N45°E and 
N70°E systems control most of the mineralization, 
although a few northwest fractures are also mineralized. 
In the Olive Camp sub-area, the mineralization is mostly 
along two general systems of northeast-trending fractures: 
(1) N 20°- 50° E and (2) N 65° - 85° E. Some of these 
fractures strike toward the San Xavier sub-area and 
although detrital cover has made it impossible to trace 
the fractures northeastward, they probably continue into 
the San Xavier sub-area.

The copper-garnet ores at the Mineral Hill mines
are closely associated with the intrusive, whereas the San Xavier lead-zinc-silver ores are farther from the intrusive. An intermediate type of mineralization is represented by the copper-zinc-silver deposits of the San Xavier Extension Copper Company. The relation of the different mines and their ore deposits to the intrusive is shown in Figure 2.

In the discussion which follows, representative mines of each type of ore deposits will be described. History and production of each mine will be given if such are available to the writer. Historical data and production figures of the mines in the area were obtained from: (1) Company reports, (2) Mineral Resources (U. S. Geological Survey) (3) Annual Report of the Territorial Governor of Arizona to the Secretary of Interior, (4) Arizona Metal Production by M. J. Elsing and R. E. Heineman, and (5) Interviews with persons familiar with the district.
Types of Ore and Their Relation to the Granite Stock

Figure 2.
Mineral Hill Consolidated Copper Company

History and Production

The original location of the claims now comprising the Mineral Hill group was made by Thomas Hughes in 1882. Under Hughes's management the mine produced about 9000 tons of high grade ore. In 1889 the Mineral Hill Mining Company took over the property and continued to develop and operate the mines. From 1889 to 1894, 4000 tons of ore were shipped to El Paso and yielded an average of 12.5 per cent copper. In 1894, this company consolidated its holdings with the Copper King Company and the latter became the operating company. The following is a list of ore shipments given in the annual report of the Territorial Governor of Arizona to the Secretary of Interior in 1899:

<table>
<thead>
<tr>
<th>Year</th>
<th>Quantity (pounds)</th>
<th>Shipped to</th>
<th>Assay(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1895</td>
<td>1,250,000</td>
<td>El Paso</td>
<td>22</td>
</tr>
<tr>
<td>1895</td>
<td>2,000,000</td>
<td>Tucson</td>
<td>12</td>
</tr>
<tr>
<td>1896</td>
<td>670,000</td>
<td>Tucson</td>
<td>12.6</td>
</tr>
<tr>
<td>1896</td>
<td>761,350</td>
<td>Copper Queen</td>
<td>11.4</td>
</tr>
<tr>
<td>1897</td>
<td>52,370</td>
<td>Tucson</td>
<td>19.3</td>
</tr>
<tr>
<td>1897</td>
<td>242,767</td>
<td>Copper Queen</td>
<td>10.7</td>
</tr>
</tbody>
</table>

On December 18, 1897 the company was reorganized at Tucson, Arizona under the laws of the Territory, with 2,500,000 shares of par value of $1.00 each. The company was then known as the Azurite Copper and Gold Company.

In January, 1898 the company installed a smelting plant consisting of two water-jacket furnaces with a
combined capacity of about eighty tons per twenty-four hours. The furnaces were in operation intermittently for two years, the aggregate of total working time being from seven to eight months. About 9600 tons of ore were smelted yielding an average of six per cent copper. The product was 800,000 pounds of matte averaging 65 to 70 per cent copper and $25.00 to $45.00 per ton in gold and silver.

On June 25, 1899 the company shipped 42,900 pounds of copper bullion and matte.

In May, 1904, the Azurite Copper and Gold Mining Company was succeeded by the Mineral Hill Consolidated Copper Company of Pittsburgh, Pa. The company owned from 50 to 60 claims; including the Azurite, Plumed Knight, and Sunrise groups.

From 1905 to the present the mines have been operated intermittently. Complete production figures for each period of activity are not available. The mines operated during the last World War and in 1916 "Mineral Resources", published by the U. S. Geological Survey, reported that the Pima district is credited with the production of 6,683,094 pounds of copper; of which "most" is stated to have come from the Azurite workings of the Mineral Hill Consolidated Copper Company.

1. Ransome, F. L., 1921, op. cit.
Elsing and Heineman gave the approximate production of the Mineral Hill Consolidated Copper Company from 1898 to 1918 as follows:

- Copper = 8,000,000 pounds
- Silver = $50,000.00
- Total Value = $2,000,000.00

The mine is developed through a vertical shaft about 700 feet deep with the principal levels at 500, 600 and 700 feet below the collar.

The company is at present owned by the Barnsdall Tripoli Corporation of Seneca, Missouri.

Character of Ore Deposits

The copper deposits of the Mineral Hill Consolidated Copper Company are of the contact metamorphic type. The ore bodies occur in limestone close to granite intrusive. The largest ore bodies were deposited along the principal fault zone (Mineral fault) and in an irregular zone of contact metamorphism near the intrusive. In general, the ore deposit has a steep southerly dip near the surface and flattens to nearly horizontal on the lower levels.

Some ore bodies extend several hundred feet from the igneous contact along fracture zones. The fractures

---

are north-south and dip steeply to the east. Some north-east and northwest fractures are mineralized with massive garnet ("garnet rock") and sulphide minerals; other un-mineralized fractures along the same trends are probably post-mineral.

The so-called "garnet rock" in the mines is not all garnet, although the mineral is an abundant constituent. It is a metamorphosed limestone containing garnet, epidote, wollastonite, and other silicates. Veinlets of quartz with other minerals cut the metamorphosed rocks. Although the writer has pointed out the close association of the copper ores with garnet, it does not necessarily follow that the same solutions caused the metamorphism of the limestone and the deposition of the ore deposits. The mere existence of garnet rock does not insure associated ore, nor is the ore by any means confined to garnet rock.

The mineralization in some less important mineralized zones in the northeastern part of the sub-area seems to be controlled by north-northeast and northeast trending fracture zones dipping rather steeply. The ore in these zones is oxidized although workings have gone to a considerable depth. No igneous rocks were observed on the dumps and it seems likely that the intrusive is at a greater depth in this part of the area.
Ore Minerals and their Paragenesis

The principal ore mineral is chalcopyrite with subordinate tetrahedrite, bornite, chalcocite, covellite, magnetite, hematite, pyrite, sphalerite, galena, and molybdenite. Sphalerite, galena, and pyrite, which are the most abundant ore minerals in the San Xavier sub-area, are very subordinate in the Mineral Hill sub-area. Molybdenite is rare.

The primary gangue minerals are garnet, epidote, wollastonite and quartz. Secondary carbonates are also present in the gangue.

The probable sequence of the minerals is as follows:

Hypogene:
- Garnet and other silicates
- Magnetite
- Hematite
- Pseudomorphic magnetite
- Quartz
- Pyrite
- Sphalerite
- Chalcopyrite
- Bornite
- Tetrahedrite
- Galena
- Molybdenite (?)

Supergene:
- Chalcocite, covellite and carbonates

Garnet, epidote, and other contact silicate minerals were deposited during the first period of mineralization, probably contemporaneous with the period of intrusion of the granite.

The first metallic minerals deposited were hematite
and magnetite. Most of the magnetite has the bladed structure of hematite, but primary magnetite, (without the bladed structure) is also present. F. N. Guild described the bladed magnetite as pseudomorphic after hematite. Guild believed that magnetite was formed first under magmatic conditions, then oxidized at considerable depths by CO₂ to hematite, and reduced again to magnetite at shallower depth.

Quartz cuts some magnetite plates. Some specimens show quartz replacing the pseudomorphic magnetite by occupying the plate boundaries. Quartz deposition probably continued for sometime for it cuts pyrite, sphalerite, and chalcopyrite.

Pyrite, the first sulphide deposited, apparently replaces pseudomorphic magnetite along plate boundaries, but in some specimens, pyrite crystals seem to be partly replaced by the pseudomorphic magnetite.

Little sphalerite is present and its relation to the chalcopyrite is not clear. The sphalerite contains scattered blebs of chalcopyrite and such relations are interpreted by some as replacements of sphalerite by chalcopyrite; others regard them as products of unmixing of solid solution.

Bornite, chalcopyrite and tetrahedrite are probably

partly contemporaneous. Tetrahedrite seems to be partly later than bornite for it is more closely associated with galena, which is one of the latest hypogene sulphides.

Galena definitely replaces sphalerite, chalcopyrite, and other earlier sulphides.

Only two specimens contained rosettes of molybdenite and from these the relation to the other sulphides is not clear. In Copper Creek, Arizona, molybdenite is the latest hypogene sulphide mineral and it is later than many gangue minerals. At Helvetia, molybdenite is later than the other sulphides, and belongs to a distinctly later period of mineralization. Molybdenite is probably a very late sulphide in the Mineral Hill sub-area.

Secondary chalcocite and some covellite are present in some specimens. Chalcocite replaces chalcopyrite along gangue boundaries. Veinlets of chalcocite are also present in the sphalerite, probably as secondary replacements in cracks of sphalerite. Thin covellite veinlets traverse chalcopyrite in some specimens.


Hypogene Stage:
- Garnet etc.
- Magnetite
- Hematite
- Pseudomorphic Magnetite
- Quartz
- Pyrite
- Sphalerite
- Chalcopyrite
- Bornite
- Tetrahedrite
- Galena
- Molybdenite

Supergene Stage:
- Chalcocite
- Covellite
- Carbonates

Paragenetic Relation of Ore Minerals in the Mineral Hill sub-area
Secondary Enrichment

Due to the reactive limestone environment, very little secondary enrichment of the ore deposits has taken place in the sub-area. When minerals like copper iron sulphides begin to break down and form sulphuric acid and ferrous and cupric sulphates, the solution immediately reacts with the limestone (CaCO₃) and forms stable minerals such as copper carbonates (malachite and azurite), ferrous carbonate or perhaps more usually hydrous ferric oxides as its final products.

Age Relations of the Ore Deposits

The ores in the sub-area are post-granite and later than the major fracture systems.
San Xavier Mine (Empire Zinc Company)

History

The San Xavier mine is one of the oldest and most extensive mines in the vicinity of Tucson. The mine was worked by "chloriders" in the early eighteen-seventies as a silver-lead property\(^1\). No attention was paid to the copper content of the ores. After being worked as a silver mine, the property was idle for a long period and the mine filled with water. It had been developed by a shaft about 300 feet deep. At 300 feet bodies of sulphide ore carrying from fifteen to twenty ounces of silver per ton, three to ten per cent copper, fifteen to forty per cent lead and twenty to twenty-five per cent zinc were known to have existed.

In 1897, General L. H. Maning reopened the mine and shipped ores to El Paso. After ascertaining the values from actual shipments and finding that the zinc was not desired by the smelters, about fifty tons of ore was concentrated with a view of separating the zinc from the copper, lead and silver. These experiments were made on the Wilfley table and the result was satisfactory.

\(^1\) Report of the Territorial Governor of Arizona to the Sec. of Interior, 1899.
Some of the mixed ore was also tested in jigs at the University of Arizona School of Mines and satisfactory separation of galena was attained. Grade of ore shipped during that time was:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>1.5 to 5 per cent</td>
</tr>
<tr>
<td>Silver</td>
<td>2 to 12 ounces per ton</td>
</tr>
<tr>
<td>Lead</td>
<td>10 to 30 per cent</td>
</tr>
<tr>
<td>Silica</td>
<td>35 per cent</td>
</tr>
<tr>
<td>Iron</td>
<td>12 per cent</td>
</tr>
<tr>
<td>CaCO₃</td>
<td>5 per cent</td>
</tr>
</tbody>
</table>

The following figures give an idea of the production during the latter part of eighteen-nineties:

Data for October, 1897

Thirty-four cars shipped contained 752 tons:

- Total Gross Value of ore = $10,237.00
- " Expense = $8,218.00
- Net profit = $2,019.00
- Net profit per ton = $2.68
- Daily average for the month = 25 tons

About fifty men were employed at the time.

In 1903, R. W. Forbes, superintendent, reported that the mine was developed to depth of 500 feet and that 100,000 tons of ore were blocked out. About 50,000 tons of ore had been shipped from the mine to 1903.

The San Xavier mine was purchased by the Empire Zinc Company in 1912 and in 1913 produced about 1500 tons of copper-silver-lead ore, which was hauled by motor trucks.

1. Report of the Territorial Governor of Ariz. to Sec. of Interior, 1899.
2. Report of the Territorial Governor of Ariz. to Sec. of Interior, 1903.
to Sahuarita and thence shipped to the El Paso smelter. Considerable oxidized zinc ore was developed during that year and the mine continued production to December, 1917. The ore shipped in 1917 carried as much as six per cent copper and six ounces of silver per ton, but the average was considerably lower. Some zinc carbonate was also produced from 1913 to 1917, mainly from open cuts.

The production of the San Xavier mine is as follows: 6,000,000 pounds of lead and $200,000.00 worth of silver; total value is $500,000.00. No figures for copper and zinc were given.

**Character of Ore Deposits**

The ores in the San Xavier mine belong to the metasomatic lead-zinc-silver type. The principal ore deposits owned by the Empire Zinc Company are located in two separate places. One group of deposits, east of the Twin Buttes highway, is developed through two main shafts, the No. 2 and the No. 3; the other group is located west of the highway and has been developed through shaft No. 6. Due to the unfamiliarity of the writer with the latter, the description of the ores will be confined mostly to the deposits below shafts Nos. 2 and 5. The writer is

of the general opinion that the two groups of deposits are similar and their genesis the same.

The shape of the deposits, below the No. 2 and No. 5 shafts, is an inverted elliptical cone with the base close to the surface. The ore bodies are not continuous but are made up of lenticular masses lying one above the other. They occur as replacements in the Permian limestone near the main east-west fault. Localization of ore shoots is controlled by two systems of fractures, the N45°E system and the N70°E system.

The ore minerals are principally sphalerite and galena with subordinate chalcopyrite and pyrite. Other minerals present are magnetite, hematite, quartz and hedenbergite.

The ore bodies in the oxidized zone are irregular masses of smithsonite, copper carbonates, jarosite, cerussite and plumbojarosite.

Paragenesis of Ore Minerals

The probable sequence of deposition of the ore minerals is as follows:

Hypogene:

- Garnet, epidote and other silicates
- Primary magnetite
- Hematite
- Pseudomorphous magnetite
- Hedenbergite
- Quartz
- Pyrite
- Sphalerite
- Chalcopyrite
- Galena
Supergene:

- Chalcocite
- Covellite
- Carbonates

Garnet and epidote are not as extensively developed in these deposits as in the Mineral Hill sub-area. They are confined to a few fissures and were apparently the first minerals to be formed.

Magnetite and hematite are also earlier than all sulphides. The magnetite-hematite relationship is similar to that in the Mineral Hill sub-area, in which the magnetite plates are pseudomorphic after hematite.

Hedenbergite is closely associated with the sulphides and although none has been observed in the polished sections this mineral is probably earlier than the sulphides.

Quartz was deposited continuously, for in specimens it is earlier and later than the sulphides. It replaces the platy structure of pseudomorphic magnetite in some samples and replaces the primary magnetite along cracks in others.

Pyrite was the first sulphide deposited. Chalcopyrite replaces pyrite along fractures. The relation of chalcopyrite and sphalerite is not clear but sphalerite is probably earlier and partly contemporaneous
**Hypogene Stage:**
- Garnet etc.
- Magnetite
- Hematite
- Pseudomorphic Magnetite
- Hedenbergite
- Quartz
- Pyrite
- Sphalerite
- Chalcopyrite
- Galena

**Supergene Stage:**
- Chalcocite
- Covellite
- Carbonates

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**Paragenetic Relation of Ore Minerals in the San Xavier mine**
with chalcopyrite.

Galena is the latest hypogene sulphide, cutting sphalerite and chalcopyrite in places.

Supergene chalcocite and covellite are relatively unimportant.

**Genesis of the Ore Deposits**

Contrasted with the Mineral Hill sub-area, the igneous bodies related to the ore deposition in the San Xavier mine are not exposed on the surface. Local men and some old mine reports mentioned the presence of "porphyry rocks" associated with the ores underground. Due to the inaccessibility of the mine workings below the water level, this information cannot be verified.

In the San Xavier Extension mine, about 1500 feet northwest of the San Xavier mine, granite porphyry sills and dikes have been encountered cutting the Paleozoic limestones. Similar bodies of igneous rocks are present in the limestones of the Vulcan mine, about 3000 feet north of the San Xavier mine. The igneous bodies are related to the mineralization and are believed to be offshoots from the main granite stock.

From these relationships, it is probably safe to conclude that the mineralization in the San Xavier mine is related to a similar source.
The mineralizing solutions, probably followed the principal northeast fractures.

Secondary Enrichment

Due to the close association of the ore minerals with the limestone, which is a reactive type of gangue, very little migration and secondary enrichment of the metallic constituents took place. Most of the metallic minerals affected by the supergene solutions were immediately converted to carbonates and silicates. Ores shipped during the early years of mining in the sub-area were from the oxidized zone, principally cerussite, smithsonite, calamine and silver associated with them. Malachite, azurite and chrysocolla are also abundant.

Relation Between the Ore Deposits of the San Xavier and the Mineral Hill Sub-areas.

In contrast to the ore deposits of the Mineral Hill sub-area, the San Xavier mine ore deposits have the following features:

1. Less garnetization and epidotization
2. More pyroxenes present
3. More galena and sphalerite and only subordinate chalcopyrite.
4. Absence of intrusive bodies close to the ore deposits.
These contrasting features of the ore deposits in the two sub-areas, less than a mile apart, present an interesting example of the zonal theory of mineralization. This feature has been observed in many ore deposits of the Rocky Mountains such as the deposit at Bingham, Utah. At Bingham, the copper ores (mostly chalcopyrite), are within the intrusive and in the sediments close to the intrusive, whereas the lead-zinc ores are in the sediments farther from the intrusive contact.

The copper-garnet ores of the Mineral Hill sub-area are close to the intrusive; the zinc-lead ores of the San Xavier area are farther from the intrusive mass.

The contact mineralization around the intrusive maybe divided into three zones:

1. Garnet zone (ferric iron) close to the intrusive.
2. Hedenbergite zone (ferrous iron)
3. Sulphide zone, farthest from the intrusive.

Mineralization at the Mineral Hill sub-area is close, to or in the ferric iron zone, whereas that of the San Xavier probably is in the hedenbergite zone, or the sulphide zone, or both.

If this zonal theory holds for the San Xavier deposits and if favorable limestone host rocks are present at greater depths, it is possible that more ore
bodies are present at greater depth, but the lead-zinc ores near the surface may grade into copper-garnet ores as the workings approach the intrusive.
Olivette Mine

General Statement

The Olivette mine, also known as the Olive mine, is included in the Corda group together with the Annette, the Collector, the Bonanza, the Happy New Year and the Arizona claims. The Olivette and the Annette claims have been most productive.

History

The Olivette and Annette claims were located in 1886 by Frank Allison, J. K. Brown, and a third party. In 1887, there was said to be about 150 men leasing within these claims. Shipments were made up to 1893.

The discovery of the mines seems to have coincided with the waning of the Tombstone district and considerable attention was given to these deposits. In 1893, the low price of silver at forty-three cents and lead at three-and-half cents per pound and the unstable demand for these metals at the same time, forced the mines to close.

During the summer of 1893 the Olivette and all other claims were deserted. Surface waters during rainy seasons began to fill the workings and caused much caving.

Estimates of production are as high as $750,000.00, largely silver.

1. From Company report.
In 1913, the Tucson Mining Company built a 100-ton concentrator at the Olivette mine, but nothing was learned of its operation.

Character and Extent of Ore Deposits

The ore deposits of the Olivette mine is typical of the silver-lead-zinc ores in narrow fissures, which are numerous in the Olive Camp sub-area.

The principal vein in the Olivette claim has a N 80° E strike and 45-degree dip to the northwest. This is crossed near the Olivette shaft by a similar vein on the Annette claim which strikes about N 80° W and dips 40 degrees to the northeast.

The Olivette and the Annette veins, like all the fissure veins in the Olive Camp sub-area, have a well marked footwall and hanging wall, about three to five feet apart with a filling of brecciated country rock. The breccia contains streaks of quartz and ore minerals. The ore shoots or "pay streaks" of high grade ore occur within the crushed gangue and breccia and ranged from two inches to two feet or more in width.

The country rock is the white Cretaceous arkose. Some dissemination of chalcopyrite, bornite, and pyrite was observed in the wall rock.

The principal ore minerals are galena, freibergite (argentiferous tetrahedrite), sphalerite and pyrite with
subordinate chalcopyrite, bornite, and chalcoocite.

The ore shipped is reported to contain from 100 ounces to 300 ounces of silver per ton with upwards of 20 per cent in lead.

The Olivette vein had been developed for several thousand feet. Several open cuts and raises reaching the surface exposed the vein. The length of the vein within the Olivette claim is roughly 150 feet. It is developed by two main inclined shafts reportedly reaching 210 feet along the incline. The two shafts are about 75 feet apart and are connected on the 200-foot level.

The Annette vein is developed by several vertical shafts of unknown depths. The workings are now filled with water to about 100 feet from the surface.

Genesis of the Ore Deposits

Mineralization took place along narrow breccia filled fractures which were probably produced by the intrusion of the granite stock. The fractures in the Olivette claim belong to the N65°-85°E system and that of the Annette belongs to the N10°-20°W system. The latter is not a prominent system and very few mineralized fissures of this system are known in the sub-area.

The ore deposits are typical shallow seated fissure deposits. Crustiform quartz, narrow vein fillings and brecciation of the materials within the fissures all
suggest this type of deposition.

The granite intrusive in the area is regarded as the source of mineralization. A small body of this rock crops out at about 800 feet northeast of the Olivette shaft and probably underlies the present workings at no great depth.

The above description of the different features of the Olivette and Annette veins applies in general to the numerous other silver-lead-zinc veins in the Olive camp sub-area.
Helmet Peak Mining and Milling Company

General Statement

The Helmet Peak Mining and Milling Company owns a group of seventeen mining claims included in the Prosperity group. The principal ore deposits are in the Elsie and Camden claims and consist of complex silver-lead-zinc ores (type 2b) in brecciated volcanic rock.

Little historical information is available, but the time of the discovery of the ore deposits and the periods of activities in the mine probably coincide with that of the Olivette mine.

Structure and Country Rock

The property lies within an area of highly altered and brecciated andesite. This rock is the green andesite referred to on the geologic map and is different from the andesitic breccia which is exposed south of the mine.

Considerable brecciation has taken place and numerous cross-faults and shear zones were observed. Hydrothermal alteration of the rock has produced chlorite, epidote and some serpentine.

Character of the Ore Deposits

The ore bodies occur as replacements in the zone of brecciation. The zone, which has a northeast-southwest trend, is approximately 250 feet in width, and has a
traceable length of several hundred feet. The ore was deposited as nodules, "pockets" and lenses in the breccia analogous to replacement ore bodies in the sedimentary rocks.

The ore minerals are galena, sphalerite, freibergite (argentiferous tetrahedrite), tennantite, pyrite, bornite, chalcopyrite and quartz. Tetrahedrite is known to be present, but in the few specimens examined only tennantite was recognized. Supergene chalcocite and covellite are also present.

Paragenesis of the Ore Minerals

The probable sequence of deposition of the ore minerals is as follows:

Hypogene:
- Quartz
- Pyrite
- Chalcopyrite
- Sphalerite
- Bornite
- Tetrahedrite
- Tennantite
- Galena

Supergene:
- Chalcocite
- Covellite
- Carbonate

Pyrite is commonly replaced by chalcopyrite and bornite forming typical "bomb-structure". Blebs of
Chalcopyrite occur in the sphalerite. Tennantite and galena replace sphalerite along cracks. Quartz had been deposited both earlier and later than sphalerite. Its relation with the other sulphides is not definite.

**Genesis of the Ore Deposits**

Like all of the mines in the Olive camp sub-area, the ore deposits of the Helmet Peak mine are probably related to the intrusive granitic stock, which underlies the area. The intrusion of the granite had probably caused the brecciation and fracturing which were later mineralized by hydrothermal solutions. Although the intrusive is not encountered on the lowest level of the mine at 600 feet from the surface, the granite outcropping not more than 3000 feet north of the mine suggests that it underlies the present workings at some unknown depth. This same granite has also been encountered by a shaft, 3500 feet northeast of the Helmet Peak mine, at a depth of about 160 feet from the surface. The stock itself crops out only three-quarters of a mile west of the mine.

**Secondary Enrichment**

Supergene chalcocite and covellite are rather abundant in the polished sections of ore samples examined. Sooty coating of chalcocite on the surface of pyrite was observed in some specimens.
Large amounts of cerussite and smithsonite were said to have been mined in the oxidized zone.

Extent of Development

The ore deposits of the Helmet Peak mine are developed by several vertical shafts and levels of varying extent. The Billings shaft is about fifty feet deep and has about 100 feet of lateral working. The Zinc shaft is seventy feet deep and was sunk near the western edge of the ore zone. Shaft No. 1 on the Camden claim is 600 feet deep. Shaft No. 2 on the Elsie claim is 400 feet in depth and about 500 feet southwest of shaft No. 1. About 3500 feet of lateral workings is said to have been done in the ore zone between shafts No. 1 and No. 2. Deepest working reached is reported to be at 600 feet from the surface.
Other Mines in the Area

**Vulcan Mine**

The Vulcan mine adjoins the property of the Mineral Consolidated Copper Company to the southwest. The mine is owned by the Vulcan Consolidated Mining Company of Tucson. The company owns the seven claims which constitute the Vulcan group.

The ore deposits belong to type 1, that is, copper deposits in the limestone not far from the intrusive contact. The geologic features of the deposits are similar to those of the Mineral Hill Consolidated Copper Company.

The mine was developed mainly by a 560-foot inclined shaft. The ore shipped from these workings in 1916 to 1917 is said to have yielded 1,200,000 pounds of copper and 11,000 ounces of silver and to have averaged six to seven per cent copper. Elsing and Heinemann\(^1\) estimated the production of copper from this mine at 700,000 pounds in 1916. This was valued at $130,000.00.

The total production\(^2\) of the mine is estimated at $500,000.00.

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2. From Company Report
San Xavier Extension Copper Company

The property of the San Xavier Extension Copper Company is about one-half mile south of the Vulcan group and about 1500 feet northwest of the No. 2 shaft of the San Xavier mine (Empire Zinc Company). The principal ore bodies lie within the Red Oxide claim.

The ore bodies occur as replacement ore shoots or lenticular masses in limestone along fractures. The ores contain principally copper, zinc and silver minerals. This type of ore probably represents an intermediate zone of mineralization between the distinctly copper-garnet ores of the Mineral Hill sub-area and the lead-zinc-silver ores of the San Xavier mine (Empire Zinc Company). "Porphyry dikes" were reported to have been encountered by underground workings.

The mine was under the management of Mr. E. G. Bush, who was also active in the development of the Twin Buttes district. In September, 1919, the mine produced about 900 tons of ore which averaged about four per cent copper and two ounces of silver\(^1\). Minerals found on the dumps are mostly sphalerite with some chalcopyrite.

The mine is developed by two shafts: an inclined shaft about 248 feet from the surface along the intrusive

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1. Ransome, F. L., 1921, op. cit.
and a vertical shaft 328 feet from the surface. The principal levels are the 227-foot level and the 312-foot level.

South San Xavier Group

The South Xavier group adjoins the Corda group on the north and the San Xavier group on the south.

The ore occurs along the east-west fault contact between the Permian limestone and the Cretaceous arkose. Very little is known of the type of ore on the production made by the mine. Examination of some specimens from the dumps showed abundant chalcopyrite and bornite.

The Gray Copper mine belongs to this group.

Swastika Group

The Swastika group, which consists of twelve claims, adjoins the Corda group (Olivette mine) on the east. The type of mineralization is similar to that of the Olivette mine. The fissures in this group belong to the N65°-85°E system. Ore minerals contain principally lead, zinc and silver with subordinate copper. The paragenesis of the ore minerals is similar to that of the Helmet Peak mine.

The Richmond claim in the Swastika group is said to have produced about $50,000.00 worth of ore.
Paymaster Claims

The ore deposits of the Paymaster claims are in narrow fissure veins which strike about N80°E. Ore minerals are principally argentiferous galena with subordinate copper and zinc minerals. The veins were reported to have a westerly dip from the surface, but turn easterly at 250 feet and follow the granite-andesite contact.

The country rock is mainly the brecciated andesite, although mineralization has also taken place along the other type of andesite rocks. The workings are underlain by granite which was encountered at about 300 feet from the surface.

The Paymaster mine is one of the largest silver-lead producers in the area. Total production is estimated at $220,000.00 from 1887 to 1908.

Alpha Group

A series of northeast trending mineralized fissures occur in this group. Copper-silver predominate in some, whereas, lead-silver constitute the main values in others. The Pima Mining Company, which is within this group, is known to have produced some pyrite gold ores of type 3.
CONCLUSION

The problem of additional ores in the area depends largely upon two factors: (a) the type of rocks and (b) the type of structure below the present underground workings of the different mines in the area.

In the San Xavier sub-area, the problem is to determine whether favorable limestone horizons exist between the present workings and the main intrusive mass. The ore deposits now exposed by the underground workings are confined mostly in the Permian and Pennsylvanian formations and the presence of the Escabrosa, the Martin and the Abrigo limestones below would provide more favorable horizons for ore deposition. In considering this possibility, the type of structure and the extent and position of the igneous intrusive below the surface must be considered. The writer has presented evidence of thrust-faulting in the southern part of the area and in the surrounding region. Therefore, the possibility that the Paleozoic strata of the San Xavier sub-area (including that of the Mineral Hill sub-area) are large thrust blocks over younger beds (Cretaceous?) should be considered. If the overthrust hypothesis is true, it may
preclude the existence of more Paleozoic limestones below the thrust plane. Whether the thrust plane still exists below, or whether it is now occupied by the granitic intrusive, remains to be determined by further exploration.

Another point to consider is the extent of the granite intrusion. It is possible that at no great depth below the surface, the granite has displaced the Paleozoic limestones. If such is true, exploration beyond the contact of the Paleozoic sedimentary rocks and the intrusive is not likely to be productive as no commercial mineralization is known within the granite intrusive itself. The problem resolves itself to the determination of how much limestones exist between the granite and the present underground workings.

Similar problems exist in the Olive Camp sub-area. It has been pointed out that some of the important ore deposits in the sub-area are in the Cretaceous strata. The problem is to determine whether the Paleozoic limestones, which are favorable ore horizons, exist below the Cretaceous strata. As in the San Xavier sub-area, the problem resolves itself to the determination of the extent of the granitic intrusive. It is probable that any Paleozoic rocks below the Olive camp sub-area were displaced by the intrusive. If Paleozoic rocks exist below the camp, a depth of several thousand feet of
prospecting may be required to reach them. The thickness of the Cretaceous series is known to be from 10,000 to 20,000 feet in the surrounding region and the position in this series in the area is not certain. It is the writer's belief that the intrusive granite exists not more than a few hundred to a thousand feet below the surface over much of the area.
The Helmet Peak area is located about 22 miles south of Tucson. Sedimentary rocks include the Cambrian Bolsa and Abrigo formations, the Devonian Martin limestone, the Mississippian Escabrosa limestone, the Pennsylvanian Naco formation, the Permian Manzano and Snyder Hill formations and the Upper Cretaceous arkose, shales, conglomerates, limestones and volcanic rocks.

Igneous rocks include granite and several varieties of basalt and andesite.

The south-dipping sedimentary rocks in the Mineral Hill sub-area are interpreted as a part of the lower limb of an overturned fold, whose upper limb had been obliterated by the granite intrusion.

In the San Xavier sub-area, an east-west fault dipping $60^\circ$ to the south brought the Permian limestones in contact with the Upper Cretaceous strata.

Helmet Peak is bounded on both east and west sides by steep-angle faults. It is interpreted as a horst-type of structure.

The large areal distribution of andesitic and quartz-
itic breccia, in the southeastern part of the area, together with low-angle fault planes with the breccia formations, suggests a thrust-fault zone from which the overlying block has been largely removed.

The general systems of fracturing in the Olive Camp sub-area are as follows:

1. N20°-50°E
2. N65°-85°E
3. N10°-20°W

Systems 1 and 2 are usually mineralized.

The ore deposits in the Helmet Peak area are of three types, based on the principal metal or metals produced:

1. Copper deposits (contact metamorphic)
2. Complex lead-zinc-silver deposits
   (a) as metasomatic replacements in limestone
   (b) in fissure veins and breccia zone
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Plate III

A. Polished section photomicrograph showing molybdenite (Mo) associated with the chalcopyrite (Cp) and sphalerite (Sp) in the ore of the Mineral Hill sub-area.

Magnified 45X

Q - quartz

B. Polished section photomicrograph showing supergene chalcocite (cc) veinlets in the sphalerite (Sp). Note blebs of chalcopyrite in the sphalerite.

Magnified 90X

Cp - chalcopyrite
Q - quartz
PLATE III

A

B
Plate IV

A. Polished section photomicrograph showing tetrahedrite (T) and galena replacing sphalerite (Sp). Tetrahedrite also replaces chalcopyrite along cracks (see lower part of the section).

Magnified 48X
(Mineral Hill sub-area)

B. Polished section photomicrograph showing chalcopyrite (Cpy) replacing pyrite (Py) along cracks.

Magnified 45X
(Mineral Hill sub-area)
Plate V

Polished section photomicrograph showing supergene chalcocite (Co) replacing chalcopyrite (Cpy) along gangue boundaries. Black mineral is quartz.

Magnified 90X

(Mineral Hill sub-area)
Plate VI

A. Polished section photomicrograph showing magnetite (Mag) and chalcopyrite occupying cracks in the epidote (E) gangue.
   Magnified 45X
   (Mineral Hill sub-area)

B. Polished section photomicrograph showing chalcopyrite (Cpy) replacing pseudomorphic magnetite (Mag) along plate boundaries.
   Magnified 48X
   (Mineral Hill sub-area)
Plate VII

A. Polished section photomicrograph showing later quartz (Q) cutting sphalerite (SP). Galena (G) is also later than sphalerite.
Magnified 48X
(San Xavier mine)

B. Polished section photomicrograph showing later galena (G) cutting earlier chalcopyrite.
Magnified 45X
(San Xavier mine)
Plate VIII

A. Polished section photomicrograph showing chalcopyrite (Cpy) cutting the pseudo-morphic magnetite (Mag) plates. Note the tendency of the chalcopyrite to follow plate boundaries of the magnetite. Also note white blebs of hematite in the magnetite.

Magnified 48X

(San Xavier mine)

B. Polished section photomicrograph showing the relation between magnetite (Mag) and pyrite (Py). Pyrite apparently replaces magnetite along plate boundaries.

Magnified 43X

(San Xavier mine)
Plate IX

Polished section photomicrograph showing later quartz (Q) occupying fractures in earlier magnetite.

Magnified 45X

(San Xavier mine)
Plate X

A. Polished section photomicrograph showing "exploded bomb" structure of pyrite (py). Chalcopyrite (cp) and bornite (bn) occupy the fractures in the pyrite.

Magnified 48X

(Helmet Peak mine)

B. Polished section photomicrograph showing tennantite (tn) and galena (G) replacing sphalerite (sp).

Magnified 55X

(Helmet Peak mine)
Plate XI

A. Polished section photomicrograph showing bornite (Bn) replacing pyrite (py).
G - galena
Magnified 45X
(Helmet Peak mine)

B. Polished section photomicrograph showing tennantite (tn) occupying a crack in sphalerite (sp).
Magnified 45X
(Helmet Peak mine)
Plate XII

Thin-section photomicrograph of granite showing sericitization of the feldspars.

F - feldspar
Q - quartz
(with cross-nicols)
Magnified 28X
Plate XIII

A. Thin-section photomicrograph of brown basalt (see Ub in geologic map) showing parallel orientation of the feldspar phenocrysts. Note outlines of olivine crystals almost completely altered to a brownish-pink mineral (iddingsite?). Secondary magnetite develops on the border of the crystals.

(Without cross-nicols)

Magnified 30X

B. Thin-section photomicrograph of gray basalt (see Ub in geologic map) showing feldspar and olivine phenocrysts. Note tiny feldspar crystals in the groundmass. Secondary magnetite develops on the border of olivine crystals. Alteration of olivine is not complete and its properties are still preserved.

(Without cross-nicols)

Magnified 30X
Plate XIV

A. Thin-section photomicrograph of Gray andesite showing hornblende phenocrysts altered to hematite with the crystallographic character of hornblende still preserved. Note outlines of feldspar crystals.

(without cross-nicols)

Magnified 30X

B. Thin-section photomicrograph of Mill andesite showing abundant serpentine (s) in the rock. Note the highly sericitized and kaolinized feldspars.

(without cross-nicols)

Magnified 28X
Plate XV

A. Thin-section photomicrograph of Red Basalt showing gas cavities partially filled with calcite. Note a portion of a large feldspar phenocryst (F) typical of the rock. Dark area represents brownish-red groundmass.

(without cross-nicols)
Magnified 26X

B. Thin-section photomicrograph of a breccia rock from the Breccia Hill.

(without cross-nicols)
Magnified 30X
Plate XVI

A. Thin-section photomicrograph of the white Cretaceous arkose (see Ka in geologic Map) showing the general texture of the rock.

(With cross-nicols)
Magnified 25X

B. Thin-section photomicrograph of the Naco hornfels showing the general mosaic texture of the rock.

(With cross-nicols)
Magnified 48X
Plate XVII

A. Thin-section photomicrograph of breccia rock commonly found as fissure filling in the Olive camp sub-area.

(Without cross-nicols)
Magnified 34X

B. Thin-section photomicrograph of crustiform quartz common in the fissures of the Olive camp sub-area.

(With cross-nicols)
Magnified 43X
A. View of the western slope of Helmet Peak.

- F - fault
- Kvs - Cretaceous volcanic and sediments
- Csh - Snyder Hill limestone

B. View of Helmet Peak from the Mineral Hill sub-area.
Plate XIX

A. View of the northern slope of the Mineral Hill showing the Mineral fault.
   Cnf - Naco formation
   -Gb - Bolsa quartzite
   -Ga - Abrigo formation

B. View of the southern slope of a hill in the Mineral Hill sub-area showing the Mineral fault.
   -Ga - Abrigo formation
   Dm - Martin limestone
   Ce - Escabrosa limestone
   Cnf - Naco formation
Plate XX

A. View of the San Xavier hills from the Breccia Hill (Looking northward)

B. View of the Helmet Peak from the Breccia Hill (Looking northeast).
Plate XXI

A. View of the Escabrosa hill west of the Twin Buttes highway (San Xavier sub-area).

Ce - Escabrosa limestone
Cnf - Naco formation

B. A prospect shaft being sunk at the Mill's property on the southwestern part of the area. (Taken: March 1942).
Plate XXII

A. View of the Breccia Hill (Looking north-east). Helmet Peak on the background.

B. Closer view of the Breccia Hill showing a fault plane dipping gently to the east. Note the breccia character of the formation.
Plate XXIII

A and B Quartzite breccia in the southeastern part of the area.
Plate XXIV

Breccia rocks on the southeastern part of the area.
Plate XXV

A. The San Xavier settlement with the No. 2 shaft of the San Xavier mine on the background.

B. The Olivette shaft.
In Pocket:
5 maps
(also a photograph of Maps #1)
(photoraph not in Lang 1, but yes 8/1957)
GEOLOGIC MAP OF THE HELMET PEAK AREA
PIMA COUNTY, ARIZONA

TOPOGRAPHY FROM UNITED STATES GEOLOGICAL SURVEY, TWIN BUTTES QUADRANGLE

EXPLANATION

Sedimentary Rocks
- RECENT
  - Og
  - Ol
  - Krb
  - Recrodenite Red Beds, arkose, siltstone, and sandstone

Geologic Symbols
- Exposed Faults
- Concealed Faults
- Contact
- Fissures
- Roads
- Trails
- Shafts and Prospect Sites
- Triangulation Station
- Bench Marks

TOPOGRAPHY FROM UNITED STATES GEOLOGICAL SURVEY. TWIN BUTTES QUADRANGLE:

GEOLOGY BY M. N. MAYOJA, 1942

SCALE 1:4,400
CONTOUR INTERVAL 50 FEET
SAN XAVIER EXTENSION COPPER COMPANY

PLAN

Scale: 1" = 50 feet

Courtesy of W.M. Sheldon