THE GEOLOGY
OF
THE CALIFORNIA MINE 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

Master of Science

in the Graduate College

University of Arizona

1936

Approved: B. S. Butler, May 15-36.
Major Professor Date.

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ABSTRACT

This thesis presents the results of field work in the California mine area during 1935 and 1936.

The oldest rocks in the area are Paleozoic sediments, mostly limestones. Mesozoic rocks, consisting of Cretaceous(?) red shales and a great thickness of undifferentiated Cretaceous rocks, were deposited unconformably on the eroded surface of the Paleozoic rocks. Granite intrusion domed and faulted Paleozoic and Cretaceous (?) rocks in Laramide time. Tertiary conglomerate was deposited upon the eroded dome. Overthrust faulting and intrusion of granite porphyry followed the deposition of the conglomerate; but overthrust faulting is believed to be less extensive in this area than previous investigators have indicated. Alluvium has been deposited in the lower portions of the area since the overthrust faulting.

Two periods of mineralization are indicated; the first accompanied the early granite intrusion; the second followed the intrusion of the granite porphyry.

The total mineral production of the Santa Rita region totals perhaps $20,000,000, but the California mine area has produced only a few tons of copper-gold ore.

INTRODUCTION

Fieldwork and Acknowledgments

The field work upon which this thesis is based was done during the months from October,1935 to May,1936. The author is indebted to Drs. B. S. Butler, A. A. Stoyanow, and F. W. Galbraith for suggestions in the field and office, and to Dr. M. N. Short for assistance with the petrographic work. Dr. B. N. Moore of the U. S. Geological Survey, and Mr. R. E. S. Heineman of the Arizona Bureau of Mines offered suggestions and supplied information of value. Finally, the cooperation of his fellow students, particularly Mr. Frank Fruitman, Mr. Malcolm Roberts, and Mr. Alfred Rasor, deserves the thanks of the author.

Previous Investigation

Information concerning the areal geology of the Santa Rita and Empire ranges and the adjacent region has been accumulating since F. C. Schrader made a reconnaissance survey of the area in 1909. Sketches of individual districts, concerned mostly with economic features, preceded Schrader's work and have been listed by him in the report referred to below. Surface geology has been studied in more detail, and some careful reports have been written on scattered areas by students of the University of Arizona, but this work has not advanced to the point where correlations are possible.

Mr. Schrader, obviously handicapped by the magnitude of his assignment - 1400 square miles to be completed in less than four months, pointed out the essential features of the area, and first recognized great overthrust faulting in the Helvetia camp. The escarpment of the Empire Mountains, which was given a cursory examination only, was attributed to a high-angle, eastwardly dipping reverse fault. Mr. Roy A. Wilson, who examined the district in greater detail, recognized a compound, low-angle overthrust, similar in magnitude to the Helvetia thrust. Work by Thomas in the Rosemont area, by Moore in the Rincon Mountains, and by Brown in the Tucson Mountains has disclosed in recent years the regional extent of the overthrust faults.

No attempt has been made to correlate in detail the stratigraphy of the Santa Rita region, and a stratigraphic column is not definitely established for the area. The recognition by Dr. A. A. Stoyanow of the Snyder's Hill limestone has furnished a useful marker for the structural geologist.

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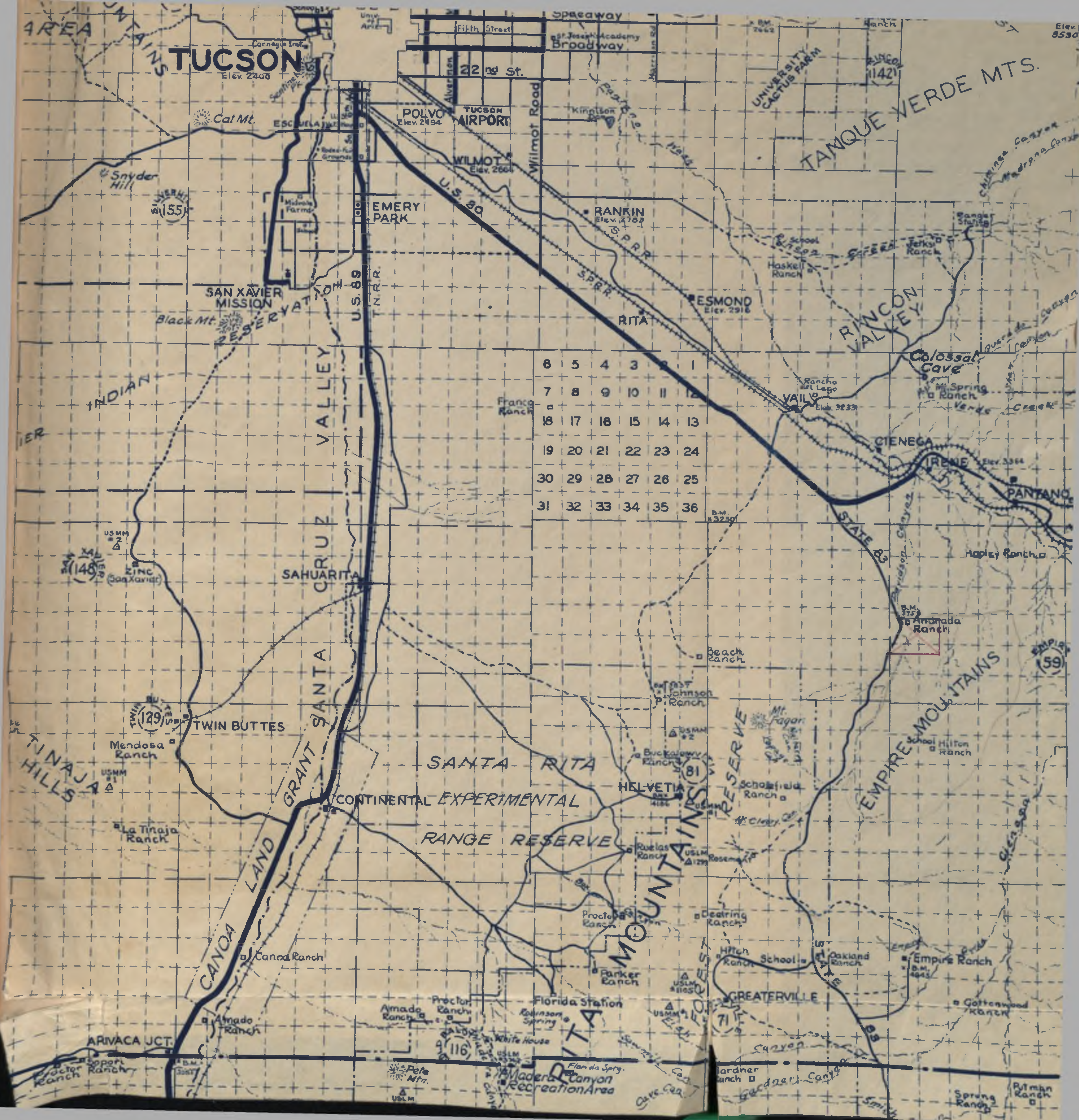

AREA
MOUNTAINS
TUCSON
Elev. 2400
Carnegie Inst.
Univ. of Ariz.
Speedway
Fifth Street
St. Joseph's Academy
Broadway
22nd St.
Alvernon
Harrison Rd.
Wilmot Road
Sentinel Pk.
Cat Mt.
ESCUELA
POLVO
Elev. 2494
TUCSON AIRPORT
WILMOT
Elev. 2664
Kinnison Dam
Pantano Wash
UNIVERSITY CACTUS FARM
RINCON
(142)
TANQUE VERDE MTS.
Elev. 8590
Chiminea Canyon
Madrona Canyon
Snyder Hill
SILVERBELL
(155)
Rodeo Grounds
Midvale Farms
EMERY PARK
U.S. 80
RANKIN
Elev. 2788
S.P.R.R.
Ranger Station
School
Jerks Ranch
Haskell Ranch
Rincon Creek
SAN XAVIER MISSION
Black Mt.
RESERVATION
INDIAN
XAVIER
U.S. 89
T.N.R.R.
ESMOND
Elev. 2916
RITA
RINCON VALLEY
Colossal Cave
Agua Verde Canyon
Posta Quemada Canyon
Rancho El Lago
VAIL
Elev. 3233
Mt. Spring Ranch
Verde Creek
6 5 4 3 2 1
7 8 9 10 11 12
18 17 16 15 14 13
19 20 21 22 23 24
30 29 28 27 26 25
31 32 33 34 35 36
Franco Ranch
CIENEGA
IRENE
Elev. 3364
PANTANO
B.M. 3250
STATE 83
Davidson Canyon
Hapley Ranch
USMM #2
(148)
ZINC (San Xavier)
SAHUARITA
SANTA CRUZ VALLEY
B.M. 3751
Andrada Ranch
Beach Ranch
EMPIRE
(59)
EMPIRE MOUNTAINS
Johnson Ranch
TWIN BUTTES
(129)
TWIN BUTTES
Mendosa Ranch
TINAJA HILLS
USMM #1
USMM #2
Mt. Fagan
SANTA RITA
Buckalew Ranch
(81)
School
Hilton Ranch
RESERVE
HELVETIA
Schofield Ranch
CONTINENTAL
EXPERIMENTAL
RANGE RESERVE
GRANT
La Tinaja Ranch
Ruelas Ranch
USLM
Rosemont
USMM #1
Mc Cleary Cn.
CANOA LAND GRANT
SANTA RITA MOUNTAINS
Proctor Ranch
Dearing Ranch
Canoa Ranch
Hilton Ranch
School
Oakland Ranch
Empire Ranch
B.M. 4645
Parker Ranch
Empire Gulch
Cienega
Florida Station
GREATERVILLE
Cottonwood Ranch
Proctor Ranch
Amado Ranch
Robinson Spring
USMM
(71)
FOREST
Amado Ranch
ARIVACA JCT.
White House
(116)
Canyon
83
Sopori Ranch
Proctor Ranch
B.M.
Pete Mtn.
USLM
Florida Spring
Madera Canyon Recreation Area
Cave Cn.
Gardner Ranch
Gardner Canyon
Smith
Spring Ranch
Putman Ranch

GEOGRAPHY

Location

The California mine lies on the northwest slope of the Empire mountains, 27 miles southeast of Tucson, Pima County, Arizona. The general region has been designated by the United States Geological Survey as the Patagonia Quadrangle, and the mines within the Empire Mountains have been included in the Empire Mining District.

The area studied lies east of the Sonoita road in Township 17 South and Range 17 East, measured from the Gila and Salt River Guide Meridian and the Phoenix Base Line. It extends 1.5 miles south from Andrade's Ranch and about the same distance east from the Sonoita road. About 2.5 square miles are thus included.

Accessibility

An excellent gravel road known as Arizona Route 83 or the Sonoita road forms the western boundary of the area. Four miles northwest of the California mine this road joins United States Route 80 leading southeast from Tucson. The nearest railroad station, Vail, lies 9 miles northwest of the area, on the main line of the Southern Pacific Railway.

Topography

The northwest slope of the Empire Mountains descends

irregularly, as a north-south line of high foothills, towards the broad and shallow Davidson Canyon. Three of the foothills occupy the eastern third of the mapped area. From their western base they rise sharply 500 feet to a maximum height of 4567 feet above sea level. The eastern slopes of these foothills are more gradual; they reach to the valley separating the mapped area from the main ridge of the Empire Mountains. The two thirds of the area west of the foothills is divided by the north-south trending arroyo known as Davidson Canyon, which is the main drainage artery of the district. The gentle slopes surrounding the Canyon are deeply dissected by tributary arroyos, but this part of the area by reason of its lower relief contrasts strongly with the higher land to the east.

To a large extent the topography has been influenced by the structure of the rocks. The smaller arroyos and Davidson Canyon itself alternately cross and run parallel to the strike of the resistant beds or otherwise follow lines of weakness. The higher portions of the area are generally the zones having the more resistant rocks - limestones and quartzites; whereas the lower portions are characteristically underlain by soft shales or granite.

Climate and Vegetation

Excepting a few mountains that rise above 7000 feet, the country has a semi-arid climate. Rainfall averages about 15

PLATE 3

Figure 1. California Mine Area looking north from Hill No. 10. Hill No. 5 at right. Davidson Canyon in middle distance.

Figure 2. Empire Mountains looking south from Hill No. 5. Hill No. 10 in right middle distance.

inches a year, according to the Forest Service, but the fall is confined mostly to the winter months and to July. Precipitation during the "summer rains" is sometimes torrential, and erosion then becomes important. Daytime summer temperatures reach 120° F, night brings lower temperatures both in summer and in winter, and in both seasons the appearance or disappearance of the sun is followed by sudden changes in air temperature. Such changes are important for their relation to weathering and the resulting physiographic forms.

Fieldwork is possible throughout the year, for even in the winter months freezing temperature is seldom reached and the days are pleasantly warm. The Weather Bureau at Tucson gives the average maximum temperature over a period of years as 108° F, and the average minimum for the same period as 17°F.

Vegetation of a sub-tropical arid type characteristic of Arizona's intermediate altitudes is found in the area. Trees include mesquite, palo verde, desert buckthorn, juniper, pinon pine, greasewood, and black oak; bushes are represented by catclaw, ocatilla, and cacti; and bear grass is fairly abundant. The following list of species has been presented to the writer by Dr. F. W. Galbraith:

Desert Broom	Baccharis sarothroides
Mesquite	Prosopis velutina
Cat-claw	Acacia greggii
Mescal	Agave chrysantha
Ocatilla	Fouquiera splendens
Creosote bush	Covillea glutinosa
Cacti	

Cacti (cont'd)	
Chollas	Opuntia acanthocarpa
	Opuntia bigelovii
	Opuntia versicolor
Prickly pears	Opuntia santa-rita
	Opuntia discata
	Opuntia engelmannii
Sahuaro	Carnegia gigantea
Rainbow	Echinocereus rigidissimus
Strawberry	Echinocereus fendleri
	Echinocereus engelmannii
Barrel	Ferocactus wislizeni
Pincushion	Neomammillaria microcarpa

HISTORY OF MINING ACTIVITY IN THE SANTA RITA AREA

The Santa Rita Mountain area has produced metal valued at nearly $20,000,000. It is not known what profit can be credited to the area as a whole, but certain properties, including the Total Wreck mine in the Empire Mountains, have been moderately successful.

Production began before the Spanish Conquest of Mexico. Mining was carried on successively by the ancestors of the Papago Indians, by the Papagos themselves under the direction of the Spanish Jesuits, and, finally, by Americans. The mining in the area during the 17th and 18th centuries was naturally a part of the great industry carried on by the Spanish throughout Durango, Chihuahua, and Sonora, in which silver was the main metal produced. The mines during this period were small, and only the richer ores were removed. Exploitation on a somewhat larger scale marked the later Spanish period up to 1820. By crude smelting methods rich copper ores like the 75 per cent ore of the Santa Rita del Cobre deposit were treated, and the presence of other base metals was established. The early Spaniards, it should be noted, had the advantage of slave labor that made possible the removal of ores from many small, isolated deposits not ordinarily considered valuable. The total metal production of the area prior to the Gadsen purchase of 1853 is not known, but presumably several hundred thousand dollars worth of silver, copper, and lead were extracted.

The Gadsen act followed by military protection from the raiding Apaches opened the Santa Rita and adjacent areas to intensive prospecting. Considerable development resulted. Rich silver-lead ore was mined at the Mowry mine in the Patagonia Mountains about 1858. At the same time silver ore averaging $1400 per ton was taken from a small pit north of Tubac, called the Heintzelman mine. The encroachments of the Apaches and other vicissitudes of Civil wartime closed all the mines of the area in the early sixties.

Resumption of activity after the Civil War was slow, but searches of the east slope of the Santa Rita Mountains gave promising results at the Rosemont and Greaterville camps. The proximity of the Empire Mountains to the Southern Pacific Railroad, which was finished in 1879, encouraged prospecting of the country around the Total Wreck mine. The Total Wreck deposit, six miles southeast of the California mine, was discovered in 1879: during the next few years it produced about one-half million dollars worth of silver and lead. By 1895 the Santa Rita area was active from north to south; Patagonia, Harshaw, Greaterville, Helvetia, and Empire camps were producing.

The first decade of the 20th century saw continued activity in the region, and the World War period was one of unparalled production of copper, lead, and silver, particularly from the Helvetia and Patagonia districts. Considerable manganese was mined at Patagonia during the war. Copper and molybdenum ores were mined at Helvetia until a few years ago. Since 1930,

however, the area has been generally quiet.

The following tables present production figures of various districts in the Santa Rita area. The figures were made available through the courtesy of Mr. R. E. S. Heineman of the Arizona Bureau of Mines and will soon be published in Bulletin 140 of the Arizona Bureau of Mines.

Table I

METAL PRODUCTION OF THE SANTA RITA AREA - (Arizona Bureau of Mines).

District	Principal Metals	Value of Production
Patagonia	Copper, lead, zinc, silver	$6,815,000
Harshaw	Lead, silver	3,835,000
Helvetia and Rosemont	Copper, zinc, lead, silver	3,320,000
Palmetto	Copper, lead, silver	2,500,000
Oro Blanco	Lead, zinc, gold, silver	1,405,000
Empire	Lead, copper, silver, gold	1,050,000
Tyndall	Lead, zinc, copper, silver	355,000*
Wrightson	Copper and lead	40,000
Total production		$19,320,000

*Approximated by writer.

* * * * *

Table II

PRODUCTION OF EMPIRE DISTRICT BY METALS (1880 - 1930)

Gold (in dollars)	$15,000
Silver (in dollars)	520,000
Copper (in pounds)	110,000
Lead (in pounds)	6,000,000

* * * * *

Table III

DETAILED PRODUCTION OF EMPIRE DISTRICT 1915 - 1933

Year	No. of Producers	Tons ore.	Gold $	Silver ounces	Copper lbs.	Lead lbs	Zinc lbs.	Total Value
1915	4	100		800		20,000		$ 2,144
1916	3			6,000		200,000		38,000
1917	5	1,528	76	9,015	1,323	326,799		35,970
1918	4	469	64	2,725	1,371	165,093	50,864	19,478
1919	2		150	8,000	1,500	30,000		53,000
1920	2		60	1,000	1,500	13,000		14,000
1921								
1922	7	746	620	7,988	9,310	178,188		19,720
1923	4	665	691	4,952	5,209	177,057		17,912
1924	5	466	157	2,352	2,262	183,215		16,686
1925	6	1,203	833	5,684	5,662	560,244	23,750	56,128
1926	7	3,461	2,764	24,983	32,066	1,566,272		148,144
1927	4	2,366	2,226	10,948	15,680	1,168,000		84,071
1928	6	1,435	1,662	5,770	14,825	645,641		44,619
1929	7	1,067	557	4,518	17,038	438,339		33,579
1930	5	356	262	2,243	6,804	164,852		10,254
1931	1	62						1,367
1932								
1933	1	5	93	3				94
Totals		13,929	$10,215	96,981	114,550	6,223,700	74,614	$595,166

STRATIGRAPHY

Sedimentary Rocks

Abrigo Limestone

Rock thought to be the metamorphosed equivalent of the Abrigo limestone occurs in Davidson Canyon about one-half mile south of the California mine. Similar rock occurs one mile east of the area, in contact with a granite intrusion.

Lithology and stratigraphic position are the bases for the classification. Positive identification is not possible because of the extreme metamorphism. The rock is distinctly banded.

Abrigo limestone showing bands of chert and limestone. Outcrop one-half mile east of Hill No. 5.

Variegated layers of brown to blue limestone, limy shale, and hard, brown to black chert are characteristic of the formation. There seems to be no marked uniformity in the bands, which are generally one-half to two inches thick; but the rock gives the general impression of alternating beds of chert and limestone or limy shale. Quantities of argillaceous material as impurities make the rock dirty in appearance and incompetent to stresses. Drag folding and other irregularities in structure are common in the metamorphosed areas. This is in sharp contrast to the purer and more massive limestones overlying the Abrigo which are less subject to folding. There is a suggestion at several places that a narrow quartzite band may form the top of the Abrigo.

As the Abrigo has been identified north of Pantano, at Tombstone, and at Rosemont, there is reason to think that the formation should be present in the Empire Mountains.

Martin Limestone

The Martin limestone has been identified at several places in the area, as near the northeast corner of the area, where unmetamorphosed fossiliferous Martin limestone occurs in the overthrust block. It is rather finely crystalline, gray in color, and thin to moderately thick-bedded. The lower part of the formation is very pure and contains few fossils. Near the top of the section is a characteristic fossiliferous zone composed almost entirely of the fossil coral Cladopora prolifica.

Even in the metamorphosed rock this zone stands out in striking contrast to the lower part of the formation, and it is therefore a valuable mapping unit. By metamorphic action the fossiliferous zone, which appears to contain original impurities, is indurated; weathering darkens it through the oxidation of iron. Parts of this zone are somewhat arenaceous and give the impression of sandstone lenses of small extent.

B. N. Moore* has found the Devonian limestones in the Tucson Quadrangle north of the Empire Mountains. In that area the Devonian is remarkably pure, and, as Moore suggests, it should produce a pure marble by metamorphism. In the Empire Mountains the lower pure portions do metamorphose to rather pure marbles with calcite crystals measuring up to one inch in maximum dimension.

Identification is based on the fossils Cladopora prolifica.

Escabrosa Limestone

The Escabrosa limestone has not been mapped as a separate unit in the area, though an attempt has been made to indicate its probable boundaries at some places. The formation is no doubt present in the area, though evidence consists only of one unnamed coral, suggestively Mississippian in age, which was found by F. W. Galbraith and the writer in the extreme northwest corner of the area.

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* Moore, B. N., oral communication.

The texture and bedding of this rock differ very slightly from those of the lower part of the Martin. The Escabrosa is equally pure, less fossiliferous, and slightly bluer in color. The contact between the Martin and the Escabrosa has been assumed to lie just above the fossiliferous zone in the Martin. The contact between the Escabrosa and the Naco is not distinct, but in the metamorphosed material it has been assumed to lie on the line separating a rather pure marble from discolored and less uniform limestone.

Naco Limestone

Naco limestone, which has not been differentiated from the Escabrosa formation in mapping, is well exposed on the eastern flank of the dome below the foothills. It occurs in several other parts of the area, as on the west flank of the dome between Davidson Canyon and the Sonoita road and in the overthrust block on Hill No. 5.

The Naco formation consists of thick-bedded, light-colored, massive limestones and extremely fine-grained, soft, pinkish-white to greenish-white, calcareous shales. The limestone beds, which are generally about 10 feet thick, are more resistant than the shales and stand above the softer members. Fossil brachiopods, crinoids, and corals are abundant in the shaly zones, but fossils are not abundant in the massive limestone. Irregular masses of chert are present that may represent fossils.

In places the formation has undergone such intense metamorphism that bedding and the blue-gray color, characteristic of the fresh, unaltered rock, are almost obscured. Silicification is intense locally along certain horizons, as along the ridge just southwest of the center of the area. In contrast to the brownish-yellow to gray or white shades of the marbleized limestone, the silicified zones are dark brown or brownish-black in color.

A zone of curiously pitted, dense, siliceous material about 100 feet thick occurs near the top of the Naco formation. This rock has undergone silicification somewhat unequally, so that areas of unsilicified limestone averaging about one inch in diameter are scattered through the dense groundmass. These residual limestone fragments have been dissolved by atmospheric water to produce a pitted surface.

The Naco limestone was identified by the fossils Axophyllum rude and Lophophyllum profundum.

Pennsylvanian (?) Shales and Schists

A roughly lenticular bed of dark shale lies between the Naco limestone and the Snyder's Hill limestone on the eastern flank of the dome. A quartz-mica schist, which is believed to be the metamorphic equivalent of the shale, lies north of the California mine.

The shale member shows a fairly sharp upper contact with the Permian limestone and a gradational lower contact with the

Naco limestone. The thickness of the shale member ranges from about 50 feet to about 200 feet. It is exceedingly variable in color and apparently in composition. In some places the rock is blackish-gray; in other places it is green, or brown, or brownish red; but everywhere it is more or less calcareous and fine-grained. Some quartzite bands are included with the shale.

The schist is a grayish-blue rock composed of light gray to white, sugary quartz, and matted, glistening, micaceous material. The color and the appearance of this rock are distinctive. The quartz, which makes up a relatively small portion of the formation, occurs as lenses and irregular bands, generally less than one inch wide, within the schistose material. In thin section the darker portions of the rock are seen to be composed of chlorite, sericite, and magnetite, in order of abundance. The sericite and chlorite are intimately intergrown in zones which are broken and irregular. Individual quartz grains show anhedral outlines and are uniformly about 0.1 millimeter in diameter. Narrow stringers of chlorite and sericite extend into the quartz bands and surround some of the quartz grains. The quartz, which appears to be a cementation of sand originally deposited as a part of the shale, is most abundant near the contact with the Naco limestone. The micaceous material and the magnetite were probably formed by the addition of material from the magma and by reworking of original components of the shale.

Gradations of schist into shale are not clearly exposed but are suggested by the structural relations along the fault at the eastern end of the schist zone. Classification of the schist as Carboniferous in age is based on an interpretation of the structure and on the correlation of the schists with the sedimentary shales.

Snyder's Hill Limestone

Snyder's Hill limestone is widespread in the area. It outcrops most conspicuously on Hill No. 10, along the base of Hill No. 5, and in the overthrust block capping Hill No. 5. The lower limestone member of the formation also occurs just southeast of Andrade's Ranch and near the Sonoita road in the southwestern part of the area.

The formation consists of three thick-bedded limestone members separated by two quartzite members.

The limestone is typically dark-blue, generally finely crystalline with yellow to white calcite developed in small cracks. Fossils are abundant in a few zones, particularly in the lower limestone member. The fossils are silicified and many are altered to black or dark-brown cherty masses. Abundant chert in certain zones may not represent silicified fossils. The rock weathers fairly uniformly. The three limestone members are similar in texture, in color, and in bedding.

The quartzite members are composed of pink or reddish-pink

to white, medium-grained, fairly pure quartzite. The upper member shows cross-bedding distinctly, but the lower quartzite is a more massive, homogeneous rock. Both quartzites break with sharp fractures and both weather brownish-red.

The two upper limestone members and the quartzite members are eroded from most of the area. In the overthrust block the quartzites are apparently thin, averaging about three or four feet in thickness. It is possible that some of the material mapped as quartzite in the overthrust block is silicified limestone.

Where the lower limestone member alone remains, it is overlain by red shales or by conglomerate of later age.

The age of the Snyder's Hill formation was established through the identification of the following Permian fossils: Composita mexicana, Archaeocidaris sp., Productus meridionalis, and Camerophoria delo~~r~~ia.

Cretaceous (?) Red Shale

A distinctive red shale member, lying unconformably upon the Snyder's Hill limestone, occurs in the northeast and in the southwest portions of the area and in the Andrade fault zone northwest of the California mine. This formation, which was apparently deposited in valleys in the Permian limestone, ranges in exposed thickness from about 450 feet to zero. The rock, as exposed on the west slope of Hill No. 5, shows irregular beds

of volcanic clastics, ranging in character from thin-bedded, fine-grained, dense, brownish-red shales to coarse, arkosic grits and conglomerates composed of pebbles of andesite, of jasper, and of dark blue limestone. A few narrow beds of dark limestone are intercalated with the conglomerate and the shale about 150 feet above the base of the formation.

Lateral changes in the character of the formation are noteworthy. At the Montana mine the equivalent of the red shales is a muddy-brown, tuffaceous sediment including tiny pebbles of jasper and arkose.

The formation is generally overlain unconformably by Tertiary conglomerate. Without this protecting cover the red shale would no doubt have been completely eroded from much of the area.

As no fossils were found in this formation, the assignment to the Cretaceous is based on stratigraphic relations and on lithology.

Undifferentiated Cretaceous Rock

In the western part of the area, bordering the Sonoita road and extending eastward to the Andrade fault, is a series of Cretaceous rocks which strike generally north 70° west and dip at low angles to the northeast. These rocks have not been differentiated in mapping, but a section of the typical Cretace-

PLATE 4.

Typical Cretaceous Section

Formation	Thickness in feet
Dark arkose	80
Andesite flow	10
Dark blue limestone	5
Fine greenish arkose	25
Light arkose	100
Light arkose, quartzite, and shale interbedded	20
White limestone	6
Brown limy shale	5
Dark greenish shale	45
Blue limestone	4
Black shale	10
White coarse arkose	35
Coarse dark arkose	40
Brown and black shale	100

ous formations as exposed along a small arroyo west of the Sonoita road is shown in Plate 4.

Arkosic sandstone is the predominant rock in this section. It outcrops conspicuously along the Sonoita road and forms resistant redges and escarpments along the arroyo which parallels the road. A fresh specimen of this rock has much the appearance of granite, but closer examination shows that the components are granular and that the distribution of the grains is not uniform. Portions of the rock mass are coarse enough to be called conglomeratic; in these portions pebbles exceeding one centimeter in length are numerous. The main rock mass and the matrix of the conglomeratic portions are composed of quartz, feldspar, and biotite. The feldspar is almost completely kaolinized and the biotite is altered to limonite. Quartz constitutes sixty per cent of the rock, altered feldspar thirty per cent, and altered biotite ten per cent. The grains are fairly uniform in size, averaging about one millimeter in diameter, and are invariably rounded. The rock is bedded with rather obscure cross-bedding. The composition of the arkose shows derivation from a granite, and the roundness of the grains indicates transportation for a considerable distance.

Thin beds of bluish-black, dense limestone, showing no fossils, and beds of black, brown, and greenish-brown shales are intercalated with the arkosic sandstone. One andesite flow lies conformably with the sedimentary beds, near the culvert along the Sonoita road.

Cretaceous limestone dipping Northeast.

Tertiary Conglomerate

A conglomerate composed of pebbles or boulders of marbleized limestone and quartzite is the predominant surface rock in the southwestern part of the area. Its extension into other parts of the Empire Mountains is not known to the writer, but it is well exposed at the Montana mine to the south and in the valley to the east of the area. B. N. Moore* suggests

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* Moore, B. N., oral communication.

its correlation with the Pantano formation of Tertiary age, which is found a few miles to the north. It may be the equivalent of the Gila conglomerate, for it appears to have been deposited under terrestial conditions from the erosion of local formations. B. S. Butler* points out the possibility that the formation may be a fanglomerate deposited locally in advance of an overthrusting block which later covered it.

Within the mapped area this conglomerate invariably lies on the Cretaceous red shales or on the Permian limestone; similar relations obtain to the east and to the south. The lower contact is an erosion surface and is nowhere conformable. The conglomerate has undergone only slight folding or faulting. The appearance of the conglomerate varies within short distances. The least altered rock contains well rounded pebbles of white limestone or marble, or pebbles of limestone and quartzite. Almost everywhere quartzite pebbles are absent at the base, but they begin to appear about twenty feet from the bottom and increase rather uniformly until they are preponderant. In a section one-half mile east of the area the total thickness of the formation is about 75 feet. Where limestone pebbles are predominant they are elongated parallel to the

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* Butler, B. S., oral communication

bedding. In places the pebbles of pure limestone are so well consolidated and cemented by lime that the conglomeratic appearance is masked. Thus at the Montana mine the conglomerate near the incline looks much like a massive limestone. Where the limestone pebbles are associated with quartzite pebbles the conglomerate is stronger and the limestone pebbles are not elongated.

Two extremes of pebble size have been found. On the top of Hill No. 11 distorted limestone pebbles, measuring about one inch in diameter, are cemented into a twenty-foot capping. This rock weathers into sharp, irregular surfaces.

Conglomerate one-half mile east of area

The other extreme is well exposed about one-half mile east of the area where an abundance of granite pebbles in addition to the quartzite and limestone characterizes the rock. The granite is no doubt the same as that in the large stock to the south and to the west of the outcrop. Near the top of the conglomerate at this outcrop the pebbles approach boulder size, measuring up to ten inches in diameter. The limestone pebbles are rounded, but the granite and the quartzite are quite angular, suggesting a very local origin.

Red shale pebbles are absent from much of the conglomerate, but along the Sonoita road just west of the mapped area a breccia-like material, which is tentatively correlated with the conglomerate, contains numerous pebbles of brownish shale, possibly the bleached equivalent of the red shale.

Nowhere in the area has material older than recently deposited alluvium been found lying above the conglomerate in sedimentary contact.

Igneous Rocks

Early Granite

A medium-grained, dark granite is exposed in the California mine area. The type specimen was obtained 200 feet west of the California mine, but identical rock and several facies of this granite are exposed along Davidson Canyon, along the northern boundary of the area, and in the valley east of the area. It has border facies of more basic nature and a few apophyses of pegmatitic and aplitic material. Thus north of the California mine a roughly banded rock of granodiorite is intruded along the limestone-schist contact. Diorite dikes in the northern part of the area and pegmatite sills in the Abrigo formation along Davidson Canyon are regarded as derivatives of the granite. This granite appears to be related to the more acidic granite stock south of the area.

In all exposures the granite is considerably altered and disintegrated, so that the original composition is partly masked. Typical rock is slightly porphyritic with a dark gray matrix of quartz, biotite, and feldspar and sporadic phenocrysts of white feldspar which measure up to five millimeters in length. In thin section the matrix is seen to be composed of about equal amounts of altered plates of biotite, anhedral grains of quartz, and subhedral grains of feldspar, all averaging about 0.1 millimeter in diameter. The biotite has been

almost completely chloritized. The feldspar, which is andesine $Ab_{66}An_{34}$, has been largely sericitized. Particles of secondary calcite averaging 0.1 millimeter in diameter are scattered through the section.

Pegmatite

A light-colored pegmatite sill about one foot thick lies in the Abrigo limestone along Davidson Canyon about three-fourths of a mile south of the California mine. Pegmatitic material also forms a dike with an outcrop about 150 feet long and six feet wide, northwest of the California mine.

The pegmatite in the Abrigo limestone exhibits graphic intergrowths of microperthite and anhedral quartz, individual blebs of either mineral ranging up to three millimeters in diameter. The absence of ferromagnesian minerals makes the rock conspicuously light colored. The microperthite, which is incipiently kaolinized, is slightly more abundant than quartz. In thin section a few tiny veins of anhedral quartz are seen to cut the graphic intergrowths.

This rock is regarded as an apophysis of the early granite.

Andesite

Andesite dikes intrude the sedimentary rocks in the northern part of the area. Northeast of the California mine

a dike follows the mineralized contact between the Pennsylvanian limestone and the Pennsylvanian schists. Along the northern base of Hill No. 5 similar dikes are found.

The andesite is a dense, greenish rock, so fine-grained that macroscopic recognition of the component minerals is not possible. Microscopic examination of the rock in thin section shows that the primary minerals in the rock are anhedral plagioclase in grains up to one millimeter in length and subhedral hornblende measuring up to 0.75 millimeters in length. Some of the feldspar, determined as andesine $Ab_{68}An_{32}$, is relatively fresh and clear, but most of the feldspar has been altered to epidote, which shows some excellent radial groupings up to 0.5 millimeters in diameter. Secondary calcite in veinlets traverses the section. The hornblende has been completely chloritized but the forms of the hornblende crystals are preserved. Some epidote has developed along the cleavage planes of the hornblende, probably by replacement of chlorite. Andesine constitutes about two-thirds of the original rock; hornblende about one-third.

These dikes are regarded as apophyses of the granite.

Andesite Porphyry

A small plug of andesite porphyry outcrops one-half mile south of the California mine, on the west bank of Davidson Canyon. This rock, which has been found nowhere else in the

area is obviously an apophysis of the granite that outcrops nearby. This facies of the granite is distinctive. Hornblende phenocrysts ranging from 0.5 millimeters to one centimeter in length lie in a groundmass of fine, white material resembling chert. The phenocrysts, arranged very irregularly in the groundmass, constitute about fifty per cent of the rock.

In thin section the phenocrysts are seen to be fresh, euhedral and subhedral hornblende that shows infiltrations of quartz. The groundmass is composed of equal parts of anhedral quartz and subhedral andesine $Ab_{65}An_{35}$, in grains averaging 0.02 millimeters in diameter. Sporadic, diamond-shaped crystals of sphene, and scattered grains of epidote are the accessory minerals.

Granite Porphyry

Granite porphyry forms the dike which follows the Andrade fault.

The rock is medium grained and distinctly porphyritic. Its most conspicuous feature is the presence of phenocrysts of glassy quartz. It is distinguished from the early granite by its lighter color, though a few acidic phases of the early granite resemble the granite porphyry. Southwest of the California mine area the porphyry apparently merges into a granite stock.

In thin section the granite porphyry is seen to consist of rather abundant, anhedral quartz phenocrysts, measuring up to three millimeters in diameter, and smaller euhedral and subhedral feldspar phenocrysts, largely altered to kaolin and sericite, embedded in a fine groundmass of quartz, feldspar, and a little altered biotite. Many of the quartz phenocrysts show rounding and embayments due to resorption by the magma which crystallized as the groundmass. The feldspar of both the phenocrysts and the groundmass is orthoclase or sanidine; feldspar phenocrysts, measuring up to one millimeter in diameter, show irregular blebs of kaolin surrounded by sericite, and the feldspar of the groundmass is largely sericitized. No fresh biotite is present, but there are a few pseudomorphs of sericite after biotite. The quartz phenocrysts compose about one-third of the rock. Feldspar phenocrysts and the few biotite pseudomorphs compose another third; and the groundmass, consisting of about equal amounts of quartz and feldspar, makes up the remainder of the rock.

STRUCTURAL GEOLOGY

General Features

The structure of the California mine area is moderately complex. Igneous rocks have intruded and domed the sedimentary rocks. The dome is well exposed in the area, though it is unsymmetrical and somewhat obscured by faults, folds, and later intrusions. Faults are more numerous than folds, but moderate folding, even of the competent beds, is conspicuous at some places in the area.

The probable sequence of events that have affected the area is:

1. Granite intrusion accompanied by doming, faulting, intrusion of pegmatite, and folding.
2. Overthrust faulting accompanied by intrusion of granite porphyry and minor high-angle faulting.

Granite Intrusion

The earliest recorded structural event in the California mine area was intrusion of the early granite, accompanied by diastrophism and metamorphism of the intruded formations.

An early stage of this diastrophism was slight folding of the deeper beds, probably by stresses set up by the approaching magma. The granite intrusion was accompanied by emplace-

ment of pegmatite sills and at a later stage by the intrusion of andesite dikes.

On the west bank of Davidson Canyon, one-half mile south of the California mine, a pegmatite sill about six inches thick is intruded into the Abrigo limestone. It was intruded before the Abrigo formation had been intensely folded, for, although the pegmatite is fractured and faulted, it is uniform in thickness on all parts of the fold, a condition that would not be expected of an intrusive following zones of weakness in previously folded, incompetent beds.

After the intrusion of the pegmatite the main mass of granite was injected. Doming, faulting, metamorphism of the limestone, and some mineralization accompanied this intrusion. Folding along generally northwest axes and intrusion of andesite dikes in the northern part of the area followed as last stages of the intrusion. The andesite dikes, unlike the pegmatite sills, are not intensely folded and fractured. These events will now be considered in greater detail.

The most conspicuous structural feature of the area is an elongated dome or northward pitching anticline that involves the entire Paleozoic and a part of the Cretaceous sections. The core of this dome is marked by the outcrops of the truncated granite stock in Davidson Canyon, south of the California mine. The flanks are outlined approximately by

the outcrops of the very white Escabrosa limestone. The longer axis of the dome seems to lie between a north-south line and a northwest-southeast line. East of Davidson Canyon the rocks swing around the core with generally easterly dips, averaging thirty to 45 degrees, whereas west of the Canyon northwest or southwest dips prevail, though the beds do not strike as regularly in that section. To the northwest the dome abuts against northeast-dipping Cretaceous rocks along the Andrade fault. To the southwest the contact of the Naco limestone with the Permian limestone seems to be a bedding fault of unknown magnitude. South of this the formations are flexed into a shallow syncline with a northwest axis. On the southwest flank of this syncline the Snyder's Hill limestone is either in contact with the granite porphyry or, as at the Montana mine, is thrust over undifferentiated Cretaceous rocks.

Permian limestone thrust over undifferentiated Cretaceous rocks.
100 yards west of the Montana Mine.

On the north also the dome appears to flatten into a shallow syncline with a general east-west axis, but this syncline is not as clearly outlined as the one to the southwest. This northern syncline is bordered on the north by another granite stock, probably connected at no great depth with the igneous core of the dome. The rocks of the eastern flank of the dome maintain easterly dips to a granite stock just east of the mapped area. Southeast of the dome is another stock of granite toward which the Paleozoic rocks, according to their location, either dip or strike. The dome as a whole, then, is surrounded on at least three sides by granite of the same age. It is plausible that the entire dome is underlain by granite at comparatively slight depth, giving to the structure the character of a roof pendant. Reference to the map (Plate 1) will show that the symmetry of the dome is destroyed by the Andrade fault on the northwest and by a number of other irregularities in structure in all parts of the area. Future work in the region may show the northwest flank of the Empire Mountains to be a monocline with dips to the east or to the north and with minor domes contained within it.

Steep-angle faulting accompanied the doming. Thus fault No. 2, which parallels the strike of the Escabrosa(?) limestone, has thrust intensely metamorphosed Escabrosa(?) beds against less altered rock of the same age. The extent of this type of faulting is probably greater than the map

indicates. The largest fault of this type is the Andrade fault. At the northern end the fault has the characteristics of a fault zone. The axis of the break runs about S 30° W from the hill just east of Andrade's ranch, crosses Davidson Canyon about 250 yards northwest of the California mine, and there bends slightly westward toward the Sonoita road. Its course is hypothetical through some of the area near the road, and apparently it becomes weaker toward the south. In the southwestern part of the area the course of the fault is believed to be marked roughly by the granite porphyry dike which has been intruded along the fault plane as explained later. The movement along this fault was reverse, bringing the Paleozoic limestones up against the Mesozoic beds. The maximum throw of the fault has not been determined. Movements have doubtless been renewed along the fault, even after the intrusion of the granite porphyry.

Folding has followed this doming. In Davidson Canyon about 250 yards southwest of the California mine is a fine exposure of folded, marbleized, Escabrosa (?) limestone resting near the granite. This fold is believed to have been partly formed shortly after the granite had solidified, though later movements have further warped the fold. The Abrigo limestone and the pegmatite sill were bent into unsymmetrical anticlines and synclines, which locally measure from crest to trough 100 feet vertically and fifty feet horizontally. The

greater folding of the Abrigo limestone was due to the incompetence of that formation. The more massive, stratigraphically higher Martin and Escabrosa (?) limestones were also folded during this period into rather sharp flexures which are best seen on the ridge southeast of the California mine near the center of the area.

Overthrust Faulting

Overthrust faulting is of fundamental importance in the California mine area. It cannot be understood completely until studied over a wider area, but some progress has been made by study of the California mine area.

Schrader recognized low-angle overthrust faulting of great magnitude in the Helvetia district, where gouge and breccia zones beneath the overthrust block are fifty or more feet thick. Thomas mapped a continuation of the Helvetia thrust in the Rosemont camp. In the Cuprite area, which lies between Helvetia and the California mine, Borland and Lee found no overthrusting, but B. N. Moore has found Paleozoic rocks thrust over Cretaceous rocks in the Tucson quadrangle near Pantano. B. S. Butler and the writer have traced an overthrust block from Pantano south toward the Empire Mountains. R. A. Wilson, who first reported overthrust faulting in the Empire Mountains, postulated a compound overthrust by which Paleozoic rocks first thrust from the southeast over

Cretaceous rocks were later covered, in part, at least, by another block of overriding Paleozoic formations. The effect was regarded as a sort of imbricated structure with a rather horizontal sole to each thrust. Wilson believed that the greater westward extension of the lower block indicated a larger movement for that block than for the upper block; presumably, the upper block had reached only as far westward as the crests of the foothills in the eastern part of the area. Wilson indicated in his sections that the lower thrust block had been intruded and metamorphosed by granite before the faulting, though he regarded the granite in Davidson Canyon as lying below the lower fault. In other words, the granite exposed in Davidson Canyon and the presumably Cretaceous rocks which it intruded there have been covered by metamorphosed limestone of the lower fault block. This interpretation of the overthrust faulting was based in part on the assignment of the limy and shaly material below the limestone at this point to the Cretaceous that is considered by the present writer to be of Cambrian age. Wilson believed the lower thrust block extended westward to near the Sonoita road and, possibly, farther.

The opinions of the present writer do not completely accord with those expressed by Wilson.

The greenish material exposed 250 yards southwest of the California mine and also one-half mile south of the mine un-

questionably lies below metamorphosed limestone and above somewhat fractured and brecciated granite. Particles of

Folded and faulted metamorphosed limestone above greenish shale and limy material.

250 yards southwest of the California mine, looking northwest.

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granite and much limy material are included in the green zone, but the granite fragments appear only near the massive granite at the eastern end of the exposure. The limy material in the zone resembles some of the Abrigo rock, but the general greenish color suggests Cretaceous formations. Movement since the intrusion of the granite has folded and fractured the rock considerably as shown at the exposure in Davidson Canyon.

The writer recognizes displacement along the zone, which he has termed the Andrade fault, but he believes a moderately high-angle, eastward dipping, reverse fault explains the known relations better than a low-angle, regional overthrust fault. If the material exposed in Davidson Canyon, described in the preceding paragraph, is of Cambrian age, as believed by the writer, there is no necessity for a low-angle, regional overthrust fault to explain the relations in this part of the area.

Along the Sonoita road just west of the area and thence south to the Montana mine the Snyder's Hill limestone is thrust upon the Cretaceous formations lying to the west. This relation is apparently inconsistent with the conception of the high-angle Andrade fault, but the relation can be logically explained by westward slipping over the Cretaceous formations of the domed Permian and younger rocks, during the larger overthrusting on Hill No. 5, and during the intrusion of the granite porphyry. This apparent anomaly will be explained later.

An overthrust block of limestone and interbedded quartzites caps Hill No. 5. This block may have been continuous with the block that caps a hill two miles southeast of the area, as was postulated by Wilson. The overthrust block is structurally complex, with bands of quartzite infolded with the massive blue limestones. Fossils of both Pennsylvanian and Permian age have been found on Hill No. 5, and Devonian

fossils have been found a few hundred yards farther east, apparently in the same overthrust block. The thrust plane is warped, but gouge and breccia, nowhere exceeding ten feet in thickness, are in places absent. On the southern flank of Hill No. 5 the thrust surface overlies the Tertiary conglomerate. Along the western edge of this hill a 25 foot to fifty foot cliff, above the Cretaceous red shales, is formed by the overthrust block. On the northwestern slope of this hill Cretaceous red shales, dipping to the northeast, are truncated by the overthrust fault. The limestones of the overthrust block also dip to the northeast at a steeper angle. Along the northern slope of this hill the Permian limestones seem to be thrust over similar Permian limestones, but the fault contact is not clear there.

The overthrust block may have extended as far west as Davidson Canyon. A block of slightly metamorphosed limestone of unknown age overlies the Cretaceous red shales along Davidson Canyon just northwest of the California mine. The limestone

Limestone overthrust on red shales in Davidson Canyon near the California mine.
Looking north.

is clearly overthrust upon these red shales, but both the limestone and the red shales have been dropped down by movements along the Andrade fault zone. This overthrust block, then, apparently truncated the northern slope of the dome.

Folding and faulting accompanied the overthrusting. Assuming that compressive forces act at right angles to the trend of a fold, it appears that the forces responsible for these folds acted along northeast-southwest lines.

The rather anomalous thrusting of the Snyder's Hill limestone over the Cretaceous rocks west of the Sonoita road, which has been mentioned previously, was no doubt a result of these same stresses. A block composed of the competent Snyder's Hill limestone, Cretaceous red shales, and Tertiary conglomerate was moved laterally westward for several hundred yards over undifferentiated Cretaceous rocks, the movement east of the Andrade fault taking place along the bedding of the weak Pennsylvanian shales. At several places south of the area a dense, siliceous material that is believed to be replaced calcareous shales underlies the Permian limestone, but along Fault No. 1 the shales are recognizable though severely crumpled. The block probably overrode the Andrade fault in the southern part of the area, but the fault was preserved in the under block and no doubt determined a line of later fracture in the upper block.

As a late stage of this diastrophism granite porphyry was intruded along the Andrade fault. It spread out laterally beneath the Snyder's Hill limestone, broke through the overthrust block as a dike, and in places it spread out laterally above the Snyder's Hill limestone, as shown north of the Montana mine. At some places along the Andrade fault the porphyry dike is not present but at other places it widens to several hundred feet.

The intrusion of the porphyry was accompanied by some further doming of the area and by some faulting. The main overthrust block on Hill No. 5 has been broken by a number of rather small faults. Fresh slickensides near the California mine indicate movement along the Andrade fault after the intrusion of the porphyry. At the exposure near the pipe line, leading from the California mine to Andrade's ranch, the overthrust limestone has been intruded by the porphyry and both rocks are cut by faults.

METAMORPHISM AND WEATHERING

General Statement

Metamorphism in the California mine area includes recrystallization of limestone to marble, silicification, sericitization, contact metamorphism, and development of schists from shales.

Conspicuous color changes have been produced by the metamorphism; originally dark limestones have been bleached to white marble or darkened by contact action to grayish-black bands; and greenish to black shales have been transformed to steel-gray schists.

Presumably, water or water vapor was the principal emanation from the intruding granite magma, but silica, alumina, and iron were added in considerable amount, and some original impurities in the limestones were reworked to form quartz and silicates. The metamorphism largely attended the intrusion of the early granite; the intrusion of the later granite porphyry was not accompanied by much alteration in the intruded rocks.

Weathering of rocks containing iron, such as the arkoses, the quartzites, and certain of the intrusives has produced red cappings over much of the area.

Alteration of the Limestone to Marble

The Martin limestone, the Escabrosa (?) limestone, and some of the Naco limestone have been altered, completely or in part, to white, crystalline marble. The coral zone at the top of the Martin limestone and the impure beds in the Naco limestone have resisted marbleization, though they have been largely silicified and sericitized. The extent of the marbleization was controlled by the purity of the limestone and by its relation to the igneous body. Emanations and heat from the magma were the direct causes of the metamorphism. Folding and faulting, which are as conspicuous in unmetamorphosed rocks as in metamorphosed rocks, effected only slight metamorphism. Marbleization is most intense near the granite intrusion, and all of the limestones in intrusive contact with the granite are marbleized.

The purest marble is milky white in color and coarsely crystalline. Rhombohedrons of translucent, milky-white calcite, measuring two centimeters across, are conspicuous in places. The crystals are generally distorted and imperfect. The cleavage faces of the positive rhombohedron invariably show traces of the negative rhombohedron.

Silicification and Sericitization of the Limestone

Much of the Naco limestone has been altered to a very

dense, exceedingly fine-grained rock which weathers reddish brown and forms resistant ridges over much of the area. In thin section this rock shows complete replacement of limestone by quartz and sericite. Individual grains are almost submicroscopic. The proportions of sericite and of quartz are about equal.

Another type of silicification, well shown on a hill northeast of the California mine, resembles quartzite in appearance but is distinguishable from quartzite by the presence of residual limestone. In contrast to quartzite, this siliceous material does not weather red but maintains a light blue to white color. It is medium grained, forms irregular, hackly outcrops, and is resistant to erosion. This type of silicification appears to be widespread in the area, but it is best developed near granite masses.

Contact Metamorphism

Contact metamorphism has produced specular hematite, epidote, wollastonite, and pyrite in zones usually less than ten feet thick on the limestone side of limestone-granite contacts. 100 yards east of the California mine a 25-foot zone of iron-stained, epidotized, and garnetized Carboniferous limestone crosses Mine Gulch. Along Davidson Canyon, one-half mile south of the California mine, a small contact zone has formed in the Abrigo limestone.

Development of Schist.

The Pennsylvanian schists in the northern part of the area have apparently been formed by the intrusive action of the early granite, which outcrops north and south of the schist. Considerable quartz has been introduced into parts of the formation and a definite schistosity has been developed.

PHYSIOGRAPHIC DEVELOPMENT

General Statement

Southeastern Arizona is a desert region marked by a series of isolated mountain ranges and broad, flat valleys. The trend of the topographic features is in general north-northwest. The Santa Rita and the Empire Mountains are in the Basin and Range province that lies southwest of the Mexican highland province. This is also known as the Sonoran Desert province. The land to the east rises very gradually to the Continental Divide in New Mexico; the country to the west slopes still more gradually to the Colorado river and to the Gulf of California.

The Santa Rita Mountains, to which the Empire Mountains by stratigraphy, structure, and position are logically related, extend for 25 miles in a generally north-south zone from the Cuprite area on the north to Patagonia village on the south. From moderate relief at the northern and southern extremities, the crest of the Santa Rita Mountains becomes higher toward the middle portion of the range, where Mt. Wrightson has an elevation of 9432 feet above sea level and 6000 feet above the adjacent Santa Cruz valley to the west. The northern third of the range, from Mt. Fagan at the northern end to the foot of Mt. Wrightson, maintains a remarkably uniform crest line at about 6000 feet elevation, from which very steep slopes descend westward to the Santa Cruz valley

PLATE 5

CONTOUR MAP OF THE

EMPIRE MOUNTAINS

and more gentle slopes lead eastward to the Empire Mountains or to the valley of Cienega creek. The portion of the range near Mt. Wrightson, comprising the center third of the mountains, is extremely irregular, but the western slopes are steeper than the eastern slopes. Sharp, deep ravines lead from the crest of Mt. Wrightson to the valleys below, and sharp peaks are conspicuous. The southern third of the range is likewise irregular and descends gradually southward to the valleys of the Santa Cruz river and its tributaries. As pointed out by previous investigators, the physiographic development of the range as a whole has been controlled closely by geologic structure.

The Empire Mountains conform generally, though on a smaller scale, to the Santa Rita Mountains. Western slopes in the Empire Mountains are conspicuously steeper than the eastern slopes. The crest line of the range rises rather abruptly from the valley to the north, maintains a fairly uniform elevation for about four miles, rises to Empire Peak, and thence leads southward to the valley of Cienega creek.

Development of Topography in the California Mine Area

Variations in the resistance and attitude of the formations have controlled almost entirely the physiographic development of the California mine area. The present features are the result of Paleozoic deposition, late Paleozoic or early Mesozoic erosion, Cretaceous deposition, Laramide diastrophism, post Cretaceous erosion, Tertiary deposition and

diastrophism, and recent erosion.

Weathering under the semi-arid conditions which have prevailed in the Santa Rita area during recent geological history tends to disintegrate rocks of non-uniform composition and to affect only slightly rocks of homogeneous composition. Precipitation under arid conditions is insufficient to dissolve limestones at the same rate that erosion removes disintegrated granite; granites thus form the lower areas, and limestones stand as ridges and escarpments.

During Paleozoic times sedimentary beds of different textures, of variable composition, and of unequal hardness were formed. Certain of these beds by reason of their greater induration and resistance to weathering and erosion stand conspicuously above softer or less resistant beds. The fossiliferous zone in the Martin Limestone thus forms a prominent crest in the lower part of the area, and variations in the hardness of Pennsylvanian formations have caused small ridges to alternate with shallow depressions on the eastern flank of the dome.

Erosion previous to the deposition of the Mesozoic rocks left hills of Permian limestone and quartzite separated by shallow valleys. Hill No. 10 was thus a hill during early Mesozoic time, though its present form is the result of recent erosion of the soft red shales which flanked and probably covered it during Cretaceous time.

Cretaceous deposits have been almost entirely eroded from the limestones and where they are present beneath overthrust limestones, as on Hill No. 5, they produce steep slopes.

Laramide disturbances formed a dome in the area. The igneous core of this dome weathered and eroded easily, and the flanks have formed gently curving ridges of moderate elevation. Faults and minor folding have determined the courses of several arroyos and the lines of small escarpments.

Post-Cretaceous erosion was followed by deposition of a conglomerate which is very resistant to erosion. This conglomerate forms the line of hills that borders the Sonoita road in the southern part of the area; it has protected Hill No. 11 from erosion and no doubt retarded erosion in other parts of the area before it was finally removed.

Thrust faulting in Tertiary time placed blocks of limestone above less resistant red shales. These blocks have protected the red shales and have formed steep cliffs like that on Hill No. 5.

Cliff formed by overthrust block of limestone above the less resistant red shales on the west slope of Hill No. 5.

HISTORICAL GEOLOGY

There is no record in the immediate area of the condition of the land at the beginning of Paleozoic time. In surrounding districts, however, the Bolsa quartzite rests on pre-Cambrian granites or upon the Pinal schist. It is supposed that the early Paleozoic conditions in the Empire Mountain area were about the same as elsewhere in southeastern Arizona - namely, the extension of shallow, muddy seas over the pre-Cambrian peneplain. The Abrigo limestone, which is the oldest formation exposed in the area, was deposited in these seas in late Cambrian time. There is no evidence of deposition in the region during the Ordovician and Silurian periods, nor is there evidence of much erosion during these periods. The ingress of the sea in Devonian time started the deposition of predominantly calcareous sediments that continued almost uninterruptedly, but with slightly changing character, until the close of Carboniferous time. The relatively pure Martin limestone of Devonian age was followed by the Escabrosa limestone of Mississippian age, by the Naco limestone of Pennsylvanian age, and by the Snyder's Hill limestone of Permian age, all in conformable sequence. With the exception of some shale and quartzite laid down in Pennsylvanian and in Permian times, which represent intervals of near-shore deposition, all of the sediments were formed in relatively deep, quiet seas in which the waters were generally warm enough to maintain abundant marine life. Between 2500 and 3000 feet of sediment was

deposited in the area during the Paleozoic era.

The recession of the seas at about the close of Carboniferous time was followed by a long period of erosion that carved the Permian formations to varying depths or removed them completely. In places within the mapped area all of the Permian quartzite and nearly all of the lower limestone member of the Snyder's Hill formation were removed. An irregular erosion surface was thus present when Mesozoic deposition began. Variegated volcanic clastics were laid down upon this surface. The source of these sediments is not known. Later in the Cretaceous period great quantities of shales, arkosic sandstones, and thinner beds of limestones and volcanics were laid down, giving a known total thickness of several thousand feet of Cretaceous rocks in the region.

During the Laramide revolution the rocks were intruded, folded, domed, and faulted. Contact metamorphism accompanied this activity and some mineralization probably followed the metamorphism.

In Tertiary time the dome was eroded and reduced locally to a rather level surface, upon which material from the surrounding hills was deposited as a conglomerate. Low-angle overthrust faulting and intrusion of granite and granite porphyry took place later in Tertiary time. This orogeny was accompanied by considerable displacement of the older structure, including further doming and faulting. Mineralization

followed the intrusion of the granite porphyry.

Weathering and erosion with the development of the present physiographic forms have marked recent geological history in the area. The stream gradients are still steep enough to prevent accumulation of great thicknesses of alluvium.

MINERAL DEPOSITS

History of Mining

Two mineral deposits of economic value have been found in the general area covered by this paper. The California mine, discovered about 1880, lies 200 yards east of Davidson Canyon in the northern part of the area. The Montana mine, discovered about 1890, lies just north of Davidson Canyon near the Sonoita road, one and one-half miles south of the California mine. Both properties are now inoperative.

For several years after its discovery, the California mine, also called the Mann mine, produced some near-surface ore containing copper and gold. In 1904, the mine was bonded to the Bradford Development Company of Los Angeles but was relinquished in 1905. Ore from the California mine was shipped to Tucson or to El Paso. It averaged about 21.5 per cent copper and $6 in gold (gold at $20.67 per ounce).

The Montana mine was originally called the Black Diamond. In 1894, John Dement and Otto Schley of Tucson developed the deposit by a ninety-foot, 30° incline and shipped about ten tons of ore averaging nine per cent copper.

The surface of the general area has been thoroughly prospected. Trenches and pits have been excavated on every spot where mineralization is indicated; several shafts ex-

ceeding fifty feet in depth have been sunk on the more favorable outcrops.

General Nature of the Mineralization

The California mine is a contact metamorphic deposit; the Montana mine is less clearly of the contact type.

The contact deposits occur at or very near the contacts of limestone and granite, though the granite is not everywhere exposed with the mineralization. The stock just south of the California mine is composed of the early granite, and the mineralization at the California mine clearly accompanied or followed the intrusion of this granite. Garnet, specularite, wollastonite, and epidote are developed in varying amounts along the granite-limestone contact, but copper mineralization is not always visibly present. At the California mine the metamorphic mineralization is intense, and copper mineralization is rather conspicuous. Copper carbonates, azurite and malachite, are the principal copper ore minerals at the California mine. The sulfide was chalcopyrite, though specimens of the mineral are not abundant. The manner of the gold occurrence is not known. The ore at the Montana mine is associated with the Permian limestone, Cretaceous clastics of volcanic origin, and Tertiary conglomerate. The nearest intrusive is granite porphyry. Most of the mineralization here appears to

be by replacement of the Cretaceous sediments beneath a roof of Tertiary conglomerate.

Periods of Mineralization

Two periods of mineralization in the area are indicated. The California deposit was undoubtedly formed by the early granite. The mineralization at the Montana mine accompanied the intrusion of the later granite porphyry. The Tertiary conglomerate is mineralized at the Montana mine, but one-half mile east of Hill No. 5; this conglomerate contains pebbles of the early granite. This corroborates the statement of Schrader* that two periods of mineralization are indicated in the Santa Rita area, the earlier probably Laramide in age, the later probably middle Tertiary.

Description of Mines

The California mine is inaccessible below the water level; the Montana mine is partly accessible. When Schrader visited the properties during the course of his work in the Santa Rita area conditions for examination were better than in 1936, and the following descriptions are based largely on Schrader's observations.

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* Schrader, F. C., op. cit., p. 87.

California Mine

The deposit at the California mine occurs in Carboniferous limestone at or near the contact with the early granite. The limestone has been marbleized, and masses of contact minerals have been developed. Three mineralized zones are distinguishable. A northern zone extends generally north-

Mine Gulch looking southeast.
Dumps of California mine in left and right centers.

eastward from the main shaft a distance of about 800 feet, dipping about 60° northwest. This zone follows the contact between the Pennsylvanian limestones and the Pennsylvanian schists, but the mineralization is confined to the limestone. No granite is exposed along this zone, but a diorite dike has been intruded at places along the contact. The zone varies in width from two feet to twenty feet, but copper mineralization is confined to a few irregular bands, each less than three inches wide. Iron and manganese stains are conspicuous in the outcrop of this zone, and malachite and azurite

form secondary coatings on the walls of shallow pits. A central zone extends 300 feet eastward from the main shaft, following the granite-limestone contact along the north bank of Mine Gulch. This zone has a variable, northerly dip and is not continuous along the contact. It terminates against or rather bends into the third or southern zone, developing at this junction into a mass of contact mineralization thirty feet wide. This central zone shows fewer copper stains than either the northern or the southern zone and appears to be mostly iron-stained, metamorphosed limestone. The southern zone strikes south 30° west from the junction with the central zone and dips 70° northwest. It lies on the contact between white marbleized limestone to the southeast and a metamorphosed limestone to the northwest. A few narrow stringers of copper minerals lie conformably with the limestone bedding along this zone. South of the main shaft across Mine Gulch a number of pits have been sunk on a mass of metamorphosed, ferruginous material which shows a few copper stains. This mass lies along the southern extension of the northern zone, though its connection with that zone is not clear. The deposit as a whole is very irregular. It appears to be controlled by a sinuous limestone-granite contact.

Chalcopyrite is the hypogene copper mineral. Quartz, specularite, epidote, andradite garnet, wollastonite, and

calcite are the principal gangue minerals. Azurite and malachite have developed by oxidation. The manner of gold occurrence is not known.

The deposit was developed by a vertical shaft sunk from a point about 35 feet above the level of Mine Gulch. A 30-foot adit, driven into the north bank of the gulch, joined the shaft 25 feet below the shaft collar. Water flows from this adit at a rate of 25 gallons per minute. On the south side of Mine Gulch, 150 feet southwest of the main shaft, is another group of workings which include an incline sloping 65° northeast, and an adit connecting the incline with the gulch. Apparently, there are no stopes in the mine. Along the north bank of the gulch and east of the main shaft, two short adits were driven into the mineralized zone. The flow of water probably deterred further work on the deposit.

Montana Mine

This deposit is smaller than the California deposit and the mineralization is less intense. The Snyder's Hill limestone beneath the deposit is not bleached, the outcrop of the orebody is not conspicuous, and the overlying conglomerate is only sparsely mineralized. The conglomerate appears to have localized solutions rising through the Cretaceous clastics from the granite porphyry. The mineralization was partly

sulfide, possibly chalcopyrite and pyrite. Carbonates are not conspicuous. The gangue at the bottom of the incline was said to be limy talcose or kaolin-like material.

The deposit was developed by a ninety-foot, 30° incline, descending 30° northeast. No water was encountered in the incline.

Economic Possibilities

Neither the California mine nor the Montana mine is likely to become a producer while copper prices are low. The only economic possibility for either property is a small production of gold-copper ore. The alleged presence of gold in ore from the California mine seems to warrant sampling of the deposit. The ore was reported to have carried twenty per cent of copper and 0.3 ounce of gold. If a considerable tonnage of material of this grade could be proved, profitable extraction could be expected.

Structural conditions at both the California mine and the Montana mine indicate shallow extent of the favorable limestone, so that any operation should be on a small scale.

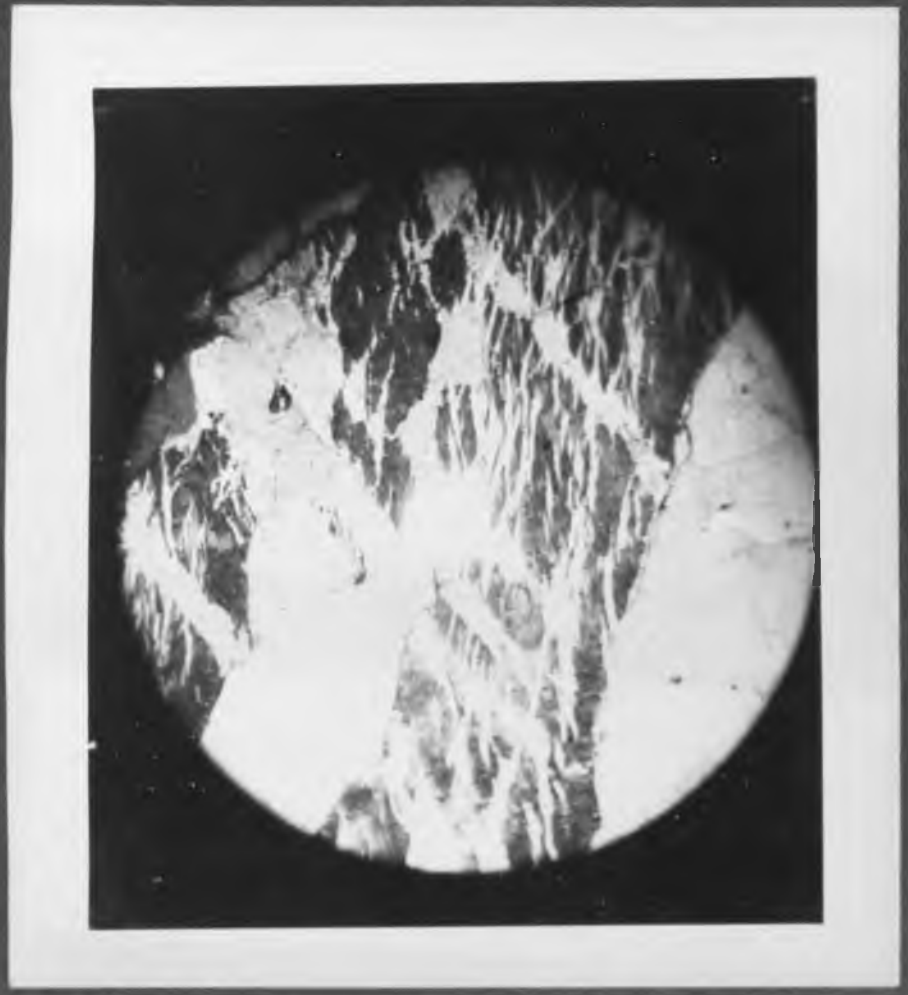
PLATE 6

Figure 1. Photomicrograph of andesite porphyry.
The dark phenocrysts are hornblende, the light mineral is mostly quartz.

Crossed nicols x 33

Figure 2. Photomicrograph of pegmatite.
The dark material is kaolinized feldspar.

Crossed nicols x 33



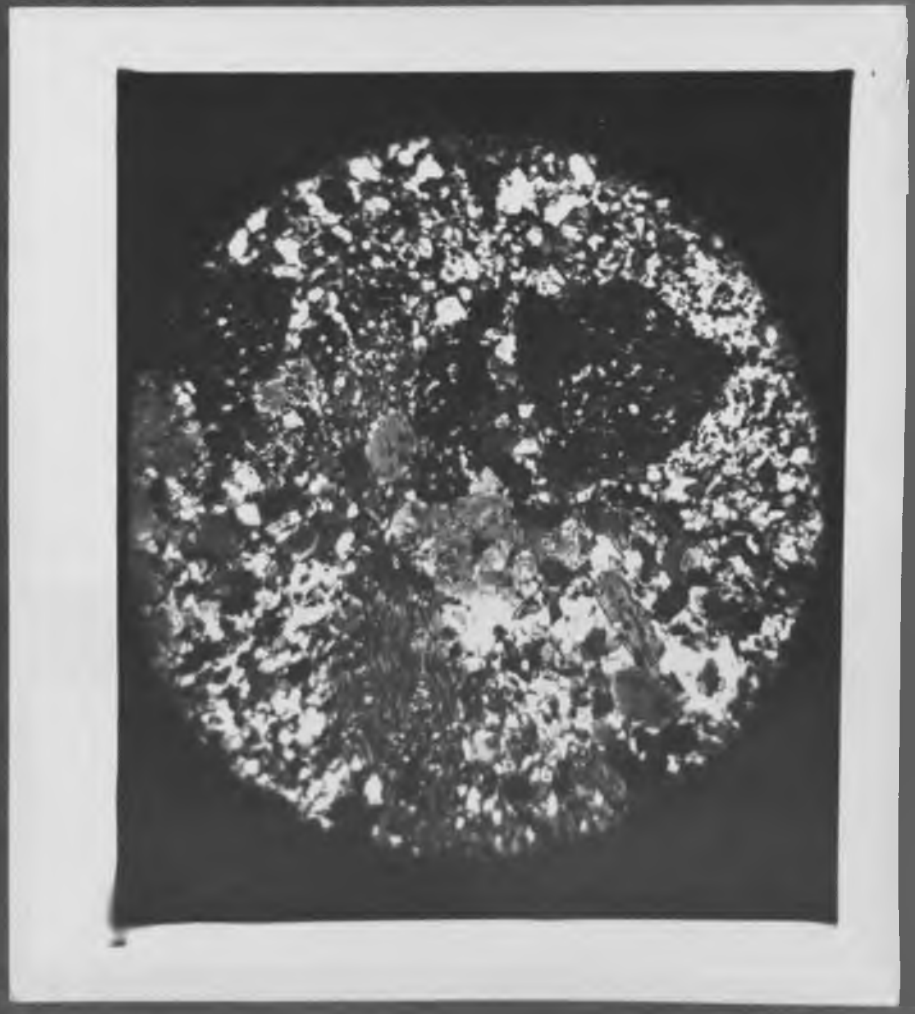


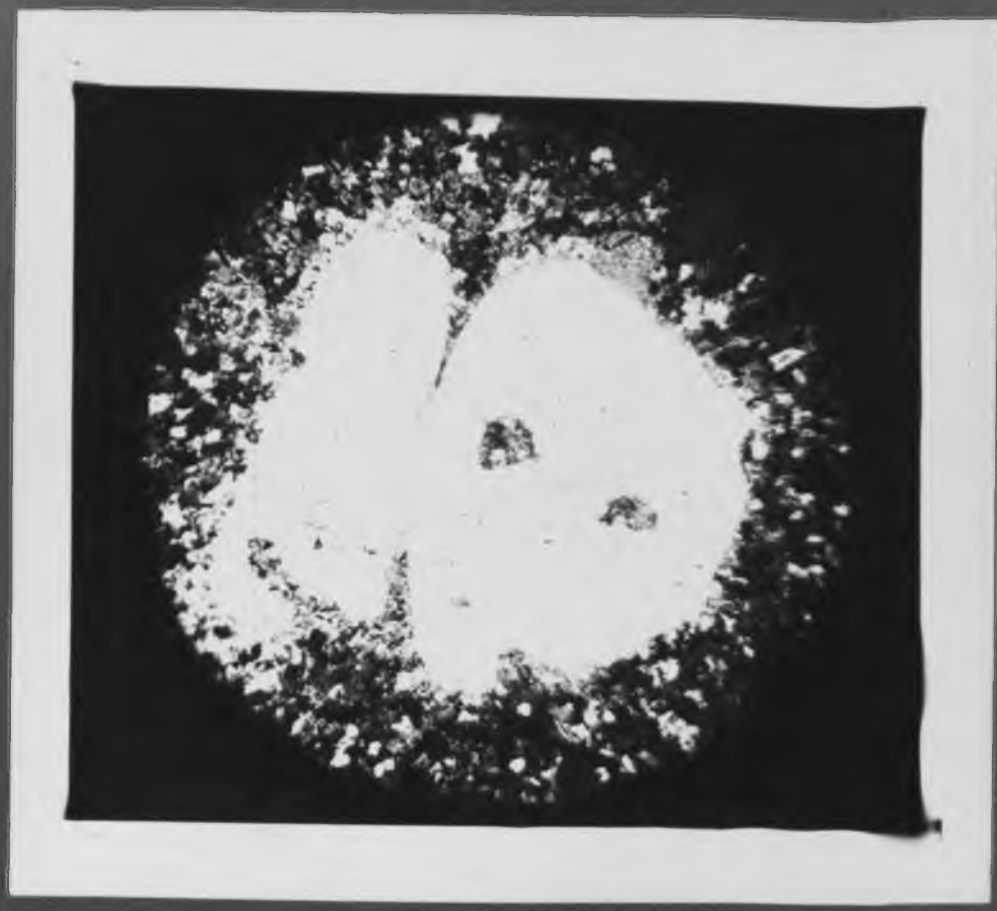
PLATE 7

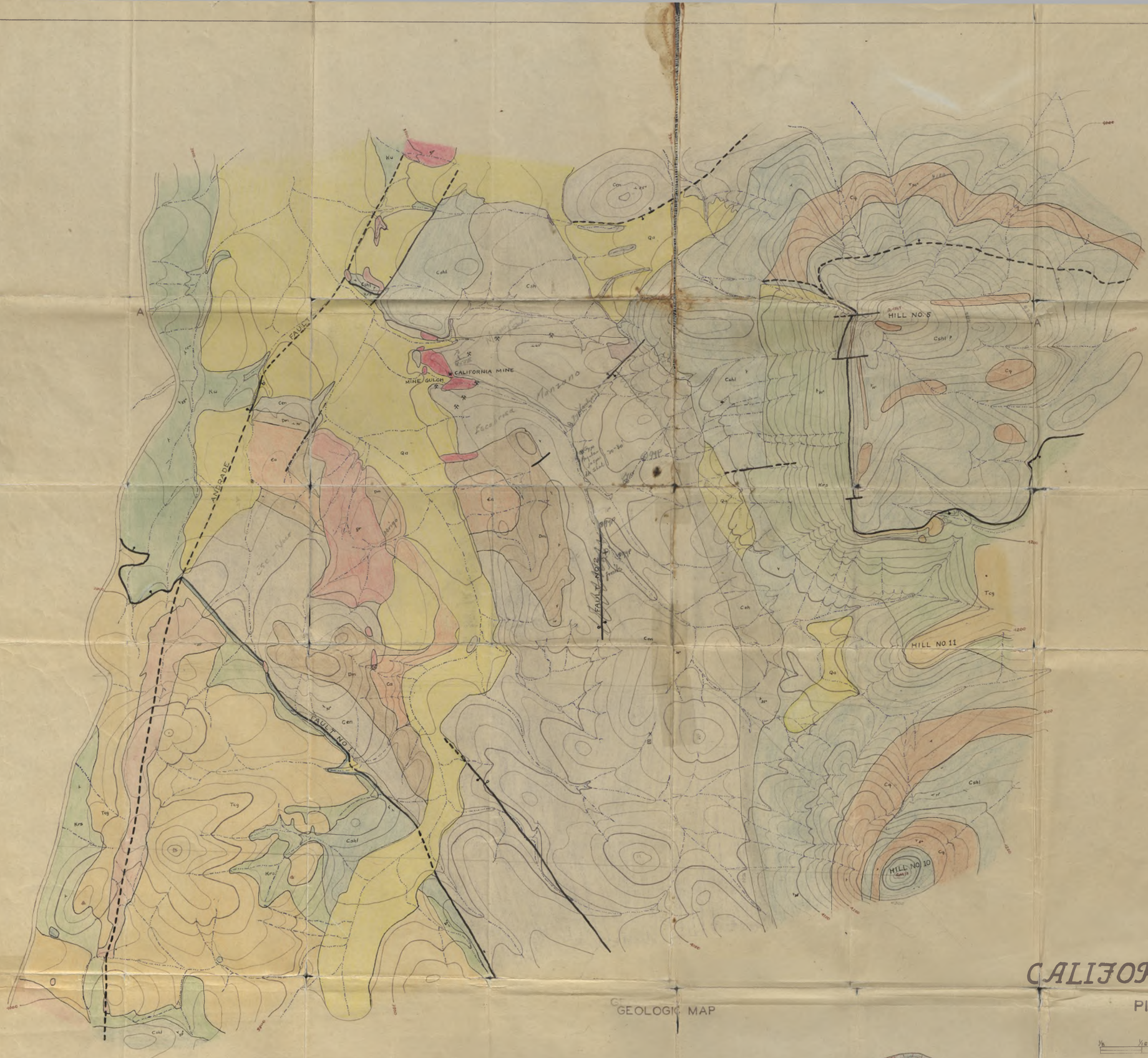
Figure 1. Photomicrograph of granite porphyry, showing the contrast in size between the quartz phenocrysts and the particles of quartz and feldspar in the groundmass.

Crossed nicols x 33

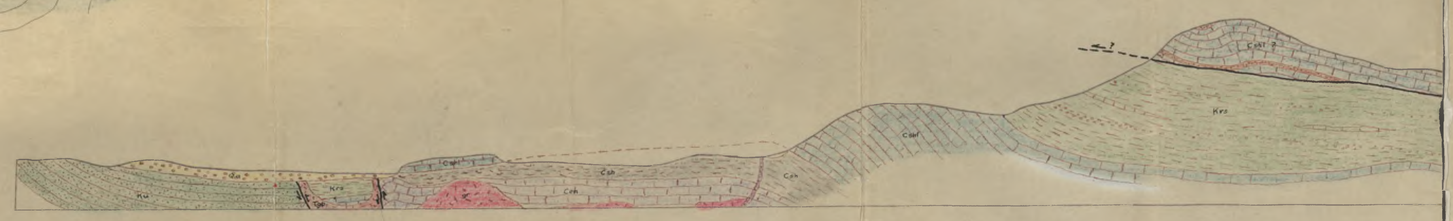
Figure 2. Photomicrograph of Pennsylvanian(?) schists. The white material is quartz, the dark material is chlorite, sericite, and magnetite.

Crossed nicols x 33





GEOLOGIC MAP



GEOLOGIC STRUCTURE SECTION
SECTION ON A-A

EXPLANATION

Sedimentary Rocks

Qa	ALLUVIUM	Tertiary Quaternary
Tcg	CONGLOMERATE	
Ku	UNDIFFERENTIATED SANDSTONES & SHALES	Cretaceous ?
Krs	RED SHALE	
Cq	QUARTZITE	Carboniferous — Permian
Cshl	SNYDER'S HILL LIMESTONE	
Csh	SHALE AND SCHIST	
Cen	ESCABROSA-NACO LIMESTONE?	Miss.-Penn Pennsylvanian (?)
Dm	MARTIN LIMESTONE	Devonian
€a	ABRIGO LIMESTONE	Cambrian

Igneous Rocks

Tgp	GRANITE PORPHYRY	Tertiary
and	ANDESITE	Cretaceous ?
gr	GRANITE	

AREAL GEOLOGY

CALIFORNIA MINE AREA

PIMA COUNTY, ARIZONA

Scale ~ 1/4800

1/8 0 1/16 1/8 1/4

Contour Interval ~ 25 feet

Datum is mean sea level

Topography and Geology by T.E. Gillingham Jr.

1936