GEOLGY OF THE SANTA ROSALIA MINE AREA
DISTRICT OF ARIZPE, SONORA, MEXICO

by

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# Table of Contents

## Introduction
- Location and accessibility  1
- Topography  1
- Climate and vegetation  2
- Water supply  4
- Field work  4
- Scope of work  5
- Previous investigations  5
- Acknowledgments  6

## Historical Geology
- Regional Geology
- General Geology
  - Divisions  14
    - Rocks of the northern division  14
      - Gooch shale  15
      - Mural limestone  17
      - Patrick conglomerate  20
      - Gateway rhyolite  23
      - Gateway tuff  25
      - Driftwood Creek conglomerate  26
      - East Ridge conglomerate  27
    - Rocks of the central division  29
      - Black basalt  30
      - Driftwood rhyolite  31
      - Green andesite  32
    - Rocks of the southern division  34
      - Fox Creek andesite  34
      - Fox Creek conglomerate  36
      - Esperanza dacite  37
      - Santa Rosalia andesite  38
      - Santa Rosalia conglomerate  40
      - Ludden andesite  42
      - Los Angeles conglomerate  43
      - Los Angeles dacite  44
### TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age relations</td>
<td>46</td>
</tr>
<tr>
<td>INTRUSIVE ROCKS</td>
<td>48</td>
</tr>
<tr>
<td>Esperanza diorite</td>
<td>48</td>
</tr>
<tr>
<td>Andesite porphyry</td>
<td>50</td>
</tr>
<tr>
<td>Rhyolite porphyry</td>
<td>52</td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>53</td>
</tr>
<tr>
<td>ORE DEPOSITS</td>
<td>62</td>
</tr>
<tr>
<td>History of Santa Rosalia Mine</td>
<td>62</td>
</tr>
<tr>
<td>Mineralization and governing structures</td>
<td>63</td>
</tr>
<tr>
<td>Zones favorable to ore deposition</td>
<td>70</td>
</tr>
<tr>
<td>Bibliography</td>
<td>71</td>
</tr>
</tbody>
</table>
ILLUSTRATIONS

Plate 1.
Geologic map of Santa Rosalia Mine area. (in pocket)

Plate 2.
Geologic map of adit level, Santa Rosalia Mine. (in pocket)

Plate 3.
Columnar section of Cretaceous sediments near Rancho Nuevo. (in pocket)

Plate 4.
Cross sections. (in pocket)

Figure 1.
Index map of northern Sonora.

Plate 5.

Figure 2.
Santa Rosalia Peak.

Figure 3.
Cretaceous limestone near Rancho Nuevo.

Plate 6.

Figure 4.
Crinkly limestone beds.

Figure 5.
Patrick conglomerate.

Plate 7.

Figure 6.
Driftwood Creek Valley.
ILLUSTRATIONS

Plate 8.

Figure 7.

Open cut

Figure 8.

Santa Rosalia conglomerate.

Plate 9.

Figure 9.

Main fault.

Figure 10.

Fault in East Ridge conglomerate.

PHOTOMICROGRAPHS

Plate 10.

Figure 11.

Esperanza diorite.

Figure 12.

Andesite porphyry

Plate 11.

Figure 13.

Esperanza dacite.

Figure 14.

Black basalt.

Plate 12.

Figure 15.

Macrospherulite in Gateway rhyolite.
ILLUSTRATIONS

Figure 16.
Microspherulite in Gateway rhyolite.

Plate 13.
Figure 17.
Esperanza diorite.

Figure 18.
Cretaceous sandstone.
ABSTRACT

The Santa Rosalia Mine area is located 16 miles northwest of Arizpe, Sonora, Mexico. The oldest rocks exposed are Lower Cretaceous. The upper limestones are correlated with the Mural limestone of Bisbee. Most of the area described is covered by Cretaceous (?) and Tertiary (?) volcanic conglomerates and altered lava flows. The flows range in composition from basalt to rhyolite, but most are andesite. All the formations are cut by Tertiary (?) intrusives. The regional dip of the formations is eastward.

The structure in the Santa Rosalia Mine area is the result of extensive faulting. The major fault system has an east-west trend and divides the area into three divisions which have no formations in common. A secondary trend is generally north-south. All are high-angle normal faults. The Santa Rosalia vein is a branch from a major fault. The mineralization is believed to have been derived from the Esperanza diorite, which is an intrusive of Tertiary (?) age. A minor amount of mineralization is associated with andesite porphyry dikes, also of Tertiary (?) age.

The Santa Rosalia Mining Company expects to start mining and milling operations in 1948.
INDEX MAP OF NORTHEASTERN SONORA

Fig. 1.
INTRODUCTION

Location and accessibility

The Santa Rosalia Mine is located in the State of Sonora, 62 miles south of Cananea, Mexico (See Fig. 1). It is 16 miles northeast of Arizpe, and 13 miles south of the San Antonio Ranch.

The mine is reached by the Arizpe road from Cananea to the turn-off on the mine road, which is about 5 miles north of Bacanuchi, thence by the San Antonio Ranch to the mine.

The roads in this area are similar to those found in most parts of Mexico. They are rough but passable except during the heavy thunderstorms that fall during the summer months. During that season a traveler should provide himself with a shovel, a lunch, and ample time for delays.

Topography

The terrain around the Santa Rosalia Mine area is rough. The relief is not great, the maximum being about 700 feet, but the slopes are steep and generally covered with talus which makes walking difficult and travel on horseback impossible except in the arroyos and lowlands. The elevation of the adit of the mine is 3705 feet, with Santa Rosalia Peak (See Fig. 2) immediately behind it rising to 4140 feet above sea level.

The area described lies within the angle of an "L"
formed by a large mass of granitic intrusive on the west and south. This intrusive forms a long narrow ridge which reaches an estimated elevation of 5500 to 6000 feet. The longer part of the "L", which extends north-south, is about 10 miles in length. The shorter part, which extends east-west, is about 3 miles in length. This structure forms a sort of two-sided basin which holds the mine and the area around it. The mine is from 2 to 3 miles from the foot of the ridge.

The rain which falls on the north side of the east-west part of the "L" is drained off by way of Arizpe Creek, which is about a mile south of the mine. The south part of the area studied, as well as an area to the west, is drained by Fox Creek which runs into Arizpe Creek about a mile from the mine. The northern part of the area is drained by Santa Rosalia and Driftwood Creeks, which also empty into Arizpe Creek. A low divide north of the Rancho Nuevo turns the waters of that area north before they swing to the east. Thus, all the rainfall over a considerable area drains by Arizpe Creek into the Sonora River at Arizpe.

Inasmuch as the rainfall is seasonal, Arizpe Creek is dry during the greater part of the year and is used as a road from the mine to Arizpe.

Climate and vegetation

The climate is typical of the arid Southwest. The
temperature ranges from a maximum of about 110 degrees in the summer to somewhat below freezing in the winter.

Rains are of the seasonal variety. Violent thunderstorms with heavy downpours are an almost daily occurrence during the summer months. They usually start in June, increase in regularity and violence until the latter part of August. Only light and infrequent rains occur during the rest of the year, mostly in early spring.

Conspicuous among the types of vegetation are many varieties of cactus, such as the tiny pincushion, the organ pipe, the prickly pear, and the vicious cholla. In some localities, as around the mine, chollas grow in such profusion that few creatures can safely traverse the area. For a man to attempt it is out of the question. Ocotillo, mesquite, yucca, paloverde, and live oak are abundant. Cottonwoods and other larger trees, which demand more water, grow in the larger creeks.

A wide variety of coarse grasses flourish when rainfall permits. Ranching, which is the principal industry in the region, is dependent entirely upon these grasses for cattle feed.

Wildlife is plentiful in the region. Most commonly seen are rabbits, deer, mountain lion, chulo, quail, dove, and a variety of small birds. Numerous striped grass snakes are present, but rattlesnakes are very few.
Water Supply

Water in this region is difficult to obtain. That necessary for employees of the mine is drawn from a well in Driftwood Creek and carried to the camp on burros. The company expects to get sufficient water for milling from another well in Fox Creek and from the mine itself.

There is about 425 feet of highly acid water in the mine shaft which must be pumped out to allow an inflow of usable water. Special pumping equipment is required because of the acid content of the water. Available records indicate a daily inflow of approximately 20,000 gallons.

Field Work

The field work upon which this thesis is based was done, for the most part, during the summer of 1947. Laboratory work and writing of the paper were done during the school year 1947-1948.

No topographic map of the region existed when the work was started, consequently, the making of one was the first part of the project. A triangulation net was laid out in the spring of 1947 and the topography drawn, by means of a plane table, during the early summer. The altitude was taken from a mine map made by T. Greenwich in 1912.
pletion of the topographic map. This work consumed most of the rest of the summer of 1947.

**Scope of work**

An attempt has been made to subdivide and classify the great thickness of volcanic rocks in this area; to work out the principal structures; to ascertain the source of the mineralizing solutions; the most favorable horizons for ore deposition, and the structural control, if any, shown in the deposits.

The sedimentary rocks were included to show their relationship to the volcanics and to determine as closely as possible the age of the volcanics. They have been dealt with much more lightly than their importance deserves, but will provide an interesting and important study in the future. Their presence has been virtually unknown heretofore.

The work done is minute as compared to the vast amount of work which must be done in this region before the geology is thoroughly understood, but it will serve as a starting point for future studies.

**Previous investigations**

No work of a geological nature has previously been done anywhere in the vicinity of the Santa Rosalia Mine. Some
surveying was done underground in 1912, but as most of the workings are under water at this time, the level maps were of no help. The map of the adit level made at that time is incomplete today, and was incorrect when made. The level map which is included with this paper is a tape and brunton survey made by the writer. The nearest areas that have been studied from a geological standpoint are Cananea and El Tigre, both of which have little in common with the area covered in this paper.

Acknowledgments

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Grateful acknowledgment is given R.W. Ludden who helped lay out the triangulation net, and my wife, Clara B. Moore, who operated the plane table during all of the topographic mapping.

Thanks are due Bill Gooch, of the San Antonio Ranch, for the generous loan of his horses, which aided materially in the rod work and in the transportation of equipment.
HISTORICAL GEOLOGY

Parts of northern Mexico have been covered by seaways during Cambrian, Carboniferous and Cretaceous time. Whether Ordovician, Silurian and Devonian strata are present is as yet unknown. However, Devonian limestone is present at Bisbee, which is 10 miles north of the International Boundary. The time of maximum inundation and deposition was the Cretaceous when the seas covered a vast area in Mexico and the United States.

While no Paleozoic rocks have been found in the area described in this paper, a thickness of 2300 feet has been reported at Cananea, 62 miles north, and 5500 feet of upper


Paleozoic strata are reported present at El Tigre Mine, about 70 miles to the east, with the base unexposed.


There are 5240 feet of Paleozoic rocks at Bisbee, Arizona, which is about 100 miles north of the studied area.

In view of the surrounding outcrops of Paleozoic strata, and their considerable thickness, it seems not unlikely that part of the section may be present somewhere north of the Santa Rosalia Mine but has not yet been reported.

Cretaceous sediments are rather widespread and of considerable thickness in this general region. At Bisbee there are over 5000 feet of Lower Cretaceous deposits, but Upper Cretaceous beds are absent. The Cabullona Series contain a maximum of 17,000 feet of Upper Cretaceous strata, and at El Tigre 2850 feet of Lower Cretaceous rocks are reported.


5. Imlay, R.W., op. cit.

A section measured by the writer 3 miles north of the Santa Rosalia Mine contains 4838 feet of Lower Cretaceous limestones and shales.

At Cananea no strata of Cretaceous age are known. Only
beds of Carboniferous age are recognized in that area, and if the Cretaceous seas ever covered that part of Sonora, as they probably did, evidence of their presence has since been removed by erosion.

In discussing the margin of the Trinity (Lower Cretaceous) sea, Imlay says: "The submarginal character of the

Trinity faunas and deposits near Sahuaripa and El Tigre indicates that the shore line extended northward across eastern Sonora. The possibility of a westward embayment between these areas is precluded by the great thickness of the deposits which proves the existence of a fairly large and rising land mass to the west. The characteristics of the Bisbee group in northern Sonora and southern Arizona show that the Trinity shore line turned westward near El Tigre and traversed the side of the northern part of the Sierra de los Ajos".

The finding of the Lower Cretaceous strata in the Santa Rosalia-area (see Fig. 1) places the western margin of the Trinity sea at least 70 miles farther west than is indicated by Imlay. Since it also appears west of the San Francisco intrusive, which forms the "L"-shaped ridge previously mentioned, the margin probably was more nearly a 100 miles farther west. This can only be determined by more field work in the western area. This new section also places the margin some 40 or more miles southwest from the Sierra de los Ajos (see Fig. 1).

The Cretaceous seaways were elevated and destroyed by
the Laramide Revolution, which closed the Mesozoic era. Intense volcanic activity accompanied the diastrophism.

In the Santa Rosalia area, as in much of northern Sonora, it is not possible to determine whether the time of volcanism was late Cretaceous or early Tertiary since the Laramide orogeny undoubtedly continued on into Tertiary time. Imlay states that the oldest lavas in northeastern Sonora are probably of early Tertiary age. In the Little Hatchet Mountains of southwestern New Mexico, Lasky has found over 5000 feet of lavas interbedded with the sediments, limestones, sandstones, shales, which are of Glen Rose, or Lower Cretaceous age. In view of this, it seems rather premature to assign all volcanic activity in Sonora to the Tertiary.

Following the deposition of the Lower Cretaceous limestone in the Santa Rosalia area was an erosional period of unknown length. This is represented by a thin limestone
conglomerate overlying the upper limestone bed. Above the conglomerate, with the same general dip as the limestones, is a thick series of water-laid tuffs and volcanic conglomerates.
The geology of the region surrounding the Santa Rosalia Mine is unknown. The published maps show no sedimentary rocks, but indicate that the entire area is covered by lava flows. There is, however, a considerable thickness of sedimentary strata.

Approaching the Santa Rosalia Mine from Cananea the sedimentary rocks are reached about 18 miles north of the mine. Beds of conglomerate are first to appear. No study or examination of these beds has yet been made, but it is possible that they correspond to the Glance conglomerate of Bisbee. The Glance is known to extend as far into Sonora as the Cabullona area (see Fig. 1), but has not been reported farther south.


Limestone first occurs about 15 miles north of Santa Rosalia mine. No study has been made of these beds other than to determine the age as Lower Cretaceous. The limestone is exposed along the road for some distance, and some of the strata shows a peculiar type of bedding. It consists of thin, wavy, or crinkly beds from 1 inch to 2 inches thick with many nodular-like thickenings which give it a sort of
conglomeratic appearance when viewed from a distance. The beds are between shale beds and probably represent a type of very shallow water deposition.

San Francisco Peak, which is about 2 miles south of the San Antonio Ranch house, is a dominating feature of the landscape. It forms the north end of the "L"-shaped granitic mass that was intruded into Cretaceous shales and limestones. A view from the top of the peak shows the strike of the sediments to be generally north-south with an easterly dip of about 30 degrees on the east side of the ridge. Cretaceous limestones and shales are also on the west side of the ridge, but the dip and strike are less prominent when viewed from a distance. They, too, are generally north-south striking but have a westerly dip.

A high ridge on the east of the San Antonio ranch house is formed by limestones and continues unbroken for about 10 miles southward. It ends about one-half mile south of Rancho Nuevo where the limestone terminates and intrusives and flows begin. The section of the sediments presented in this paper was measured near the Rancho Nuevo Ranch house. The road south from the San Antonio Ranch to the Santa Rosalia mine follows a rather narrow valley cut in soft shale beds between the limestone ridge on the east and the San Francisco intrusive on the west.

The high ridge of the intrusive turns abruptly east about 2 miles south of the mine, bounding on two sides an area of
unknown size covered by flows and fragmental rocks.

GENERAL GEOLOGY

Divisions

East-west faults have divided the Santa Rosalia area into three parts, namely, a Northern Division, a Central Division, and a Southern Division. The formations in each division are different from those in either of the other divisions. The displacement on the two normal faults that make the separation is not known, but it must be thousands of feet. The southern fault is known as the Main fault, and crosses the area just north of the Santa Rosalia mine. The northern fault, known as the Driftwood Creek fault, is parallel to the Main fault and about 1500 feet north of it.

ROCKS OF THE NORTHERN DIVISION

The only known marine deposits in the Santa Rosalia area are of Glen Rose age, and have been divided into the Gooch shale and the Mural limestone. They begin at the north-west corner of the area mapped and continue northward, in what appears to be a narrow belt, for about 15 miles. The strike of the formations is generally north-south with an eastward dip averaging about 30 degrees. The base of the strata is cut off on the west by the San
Francisco intrusive.

The marine deposit is made up of a series of inter-bedded limestones and shales, with some sandstone. A thick series of tuffs and volcanic conglomerates, whose base is marked by a thin limestone conglomerate, overlies the marine series. Their environment of deposition is uncertain but is probably also marine.

The lower part of the marine deposits is made up largely of shale separated by thin limestone members which rarely exceed 10 feet in thickness. Most of the lower limestones are shaly and impure and some have a peculiar crinkly structure that is interpreted as indicating very shallow water deposition. (Similar beds appear about 12 miles north). The thicker limestones contain abundant fossil fragments, but fossils sufficiently preserved for identification are rare. Most of the fragments appear to have been derived from oyster shells, but there are also a few recognizable gastropods.

**Gooch Shale**

The lowest member of the Gooch shale is shale with some thin interbedded sandstones. (See Plate 3). (The sandstone has not been separated from the shale in this or other shale members). It is 1060 feet thick and is bounded by an igneous contact below and the first limestone above.

Colors of the shales include dark red, gray, green and
black. Next above is a series of shale beds alternating with thin limestone beds. From one of the shale beds a fresh-water gastropod of the genus *Physa* was collected. A small spirally-coiled gastropod of a different genus was also found but identification could not be made. This particular form seemed to be relatively abundant. Whether it, too, is a fresh-water form is not known.

Lasky\(^{10}\), in describing a Lower Cretaceous section in


the Little Hatchet Mountains of New Mexico, noted fresh-water forms in the Playas Peak formation which is between massive *Orbitolina*-bearing limestones. In the Santa Rosalia area the beds containing the fresh-water forms are below the *Orbitolina*-bearing beds but marine forms occur between the *Physa*-bearing bed and the *Orbitolina*-bearing limestone.

Overlying the alternating beds of shale and limestone is 1010 feet of shale with a few thin beds of sandstone. The sandstone is fine-grained, hard, and so well cemented that it approaches a quartzite. Microscopic examination shows it to be composed of 60 per cent quartz, 30 per cent feldspar, 5 per cent calcite and 5 per cent magnetite. Two or three unaltered flakes of biotite were also noted. About 75 per cent of the quartz grains are angular to subangular. The
feldspars are more rounded, but not well-rounded. Some calcite is present as a cement, but not sufficient to be termed the cementing material. The fresh surface of the rock does not effervese.

The fourth member is composed of alternating thin limestone and shale beds. A specimen of Tylostanta was collected from the top limestone bed.

The fifth member of the marine series is the lowest massive limestone. It is exposed as a cliff in front of the house at Rancho Nuevo. The limestone is dense, massive, thick-bedded, gray to medium gray, with a thickness of 700 feet. The beds in the lower part of the member are 7 to 20 feet thick (see Fig. 3), but the upper ones are 3 to 5 feet in thickness. No fossils were found in this unit.

Above the thick limestone are 325 feet of buff to reddish shales with thin, buff, impure limestones. No fossils were found in it.

**MURAL LIMESTONE**

Overlying the Gooch shale is the lowest member of the Mural limestone. It is a massive, gray limestone 475 feet thick. The lower beds are cliff-forming in this area, as is shown in Figure 2. The lower beds are from 15 to 40 feet thick, with the upper beds averaging about 3 feet in thickness. A few specimens of *Orbitolina* were noted near the top of the member, and at the contact of the limestone with the
overlying shale a collection containing Kingena, Terebratulina, and Alectryonia was made.

The second member of the Mural limestone is a sequence of 75 feet of green, buff, and black shales with thin, interbedded, buff limestones.

A dense, thick-bedded, gray limestone, which grades to buff near the bottom, is the third member. Fragments of oysters are abundant but no specimen sufficiently preserved for collection and identification was noted.

Another shale and interbedded limestone unit, 100 feet thick, overlies the limestone.

The uppermost member of the Mural limestone is similar to the thick, gray limestone below. It, too, is dense, gray, thick-bedded, but the beds are somewhat thinner than those of the massive limestones below it, being from 5 to 10 feet thick. Near the top of this member Orbitolina and Nerinea specimens were collected.

Above the massive limestone is a limestone conglomerate about 4 feet thick which, in turn, is overlain by the Patrick volcanic conglomerate.

Limestones in the upper part of the marine series are similar in color, composition, and character. Those in the lower part of the sequence are distinctly different from the upper limestones. The lower beds are impure, buff or dark gray to almost black and occur as thin units between thick shales. In the upper part of the section the limestones are relatively pure, gray to medium gray, and occur as thick units
between thin shales.

The entire faunal assemblage in the section indicates Lower Cretaceous, or Glen Rose age. The species of Alectryonia however, has European, rather than North American, affinity. The Orbitolina, found in the massive limestone member number 7, and in the upper limestone, establishes correlation of these two, together with intervening members, with the Mural limestone of Bisbee. It is the writer's belief that the lowest massive limestone (member 5) is also Mural, but until fossils are found to prove this it must be classed only as Glen Rose.

One difference between the faunal zones of the Rancho Nuevo section and those of Bisbee, Arizona, and the Eureka district of New Mexico is the absence of a rudistid zone between, or accompanying, the Orbitolina zones.

The map of the Santa Rosalia area includes only the upper, or Mural, beds. The lower massive limestones and thick shales lie beyond the limits of the map to the north and west. The section described was measured along the creek south of the house at Rancho Nuevo.
THE PATRICK CONGLOMERATE

The Patrick conglomerate was named from the Patrick prospect (antimony) which is located on it, but which reaches down into the underlying limestone.

This volcanic conglomerate covers a rather large area in the north-western part of the mapped area. It continues to the west for an undetermined distance, but is cut off on the south by the Driftwood Creek fault. On the north it overlies steeply dipping limestone, and on the east is cut off in the north Driftwood Creek valley by an unnamed north-south fault. At the south end of the valley the formation is overlain by the Gateway rhyolite.

The Patrick conglomerate is gray to gray-green and is composed of silicified fragments of eroded flows and cherty pebbles cemented in a matrix of arkose, which is variably silicified. Near the contact of an intruding dike in Santa Rosalia creek it is so silicified that it breaks through the pebbles rather than around them. The pebbles are, in most places, small. They are rarely more than one half inch in diameter and locally are so small and few that only a careful examination will show them. The pebbles are rounded to angular and fairly well sorted. The formation shows definite bedding of a type that indicates water deposition. Beds range in thickness from a few inches to 15 feet. The formation has a total thickness of 400 feet.
Where there is little or no silicification of the matrix, the formation weathers into cliffs and slopes that are almost barren of vegetation. It weathers much like a thick-bedded, pure limestone and, because of gray color and distinct bedding, when viewed from a distance, might easily be mistaken for a limestone.

The age of the formation is uncertain. Since it unconformably overlies the Mural limestone, being separated from it by a thin limestone conglomerate, it is post-Mural. The attitude of these beds is essentially the same as that of the underlying Mural. The formation is well-stratified and water-deposited. The succeeding formations, with the exceptions of the Gateway rhyolite and the Driftwood fan-glamomerate, are also water-deposited. For a series of formations of this uniformity and thickness (over 1000 feet, plus an unknown amount of East Ridge conglomerate) to accumulate would require a large body of water in a basin sinking at a rate about equal to the rate of filling. Such a condition is not known to have existed in this area since Cretaceous time.

The Cretaceous period, according to Imlay, was ended

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with uplift accompanied by folding and faulting and the
surface of the region was eroded to high relief before Tertiary vulcanism began. In view of this, it is not likely that Tertiary sediments would so closely conform to the underlying rocks.

In view of the foregoing evidence the writer believes that these formations were laid down in an oscillating Cretaceous sea following an erosional period during which the sediments above the Mural limestone were removed. Verification can come only after a considerably wider field has been covered.
The Gateway rhyolite is a flow overlying part of the Patrick conglomerate, but is restricted in areal extent. Its outcrop extends from near the junction of Santa Rosalia Creek and Driftwood Creek to the top of the first hill north (see Plate 1). Its eastern boundary is determined in part by small faults and in part by its eastward dip underneath the Gateway tuff. Its northern boundary is erosional, but on the west it is dropped down by a fault against the underlying volcanic conglomerate.

The flow is light to medium green and in most outcrops is aphanitic. Hand specimens appear to be composed of about 25 per cent pink orthoclase which combines with the yellowish-green epidote to give the rock a soft, streaked, pinkish green color. This particular coloring effect occurs only in the aphanitic facies. Sufficient calcite is present to cause the rock to effervescence rather vigorously with acid.

In the valley of Driftwood Creek, about 800 feet north of the intersection with Santa Rosalia Creek, the rhyolite contains large spherulites. In this facies the groundmass is aphanitic, light to medium green, with no pink feldspar grains as in the aphanitic facies. Here the pink feldspar is in the form of spherulites which measure up to 6 mm. in diameter. White feldspar phenocrysts measuring up to 3 mm. are scattered through the groundmass. The effect is a
peculiar, knotty, speckled appearance. Flow structure is well developed in both facies.

Under the microscope the spherulitic facies is shown to be made up largely of spherulites though those visible in the hand specimen form not more than 10 per cent of the rock. In the groundmass around the large radiating spherulites are rings of kaolin enclosing numberless microspherulites that show the perfect cross of parallel extinction. The black of the extinction cross against the white of the spherulites gives the groundmass the appearance of a mass of black and white checks.

Epidote forms about 10 per cent of the rock. The remainder of the rock is made up of orthoclase, 5 per cent, and oligoclase, 1 per cent, with a minor amount of apatite.

While the Gateway rhyolite does not show macroscopic spherulites in all outcrops, the microscope shows the structure in every part of the flow. Spherulites are not everywhere perfectly formed, nor large, but, even in what macroscopically appears structureless, the microscope shows spherulites covering about 55 per cent of the slide. Calcite is prominent in the aphanitic facies and forms about 15 per cent of the slide. Quartz and epidote, each about 10 per cent, are present. The rest of the rock is made up of oligoclase, 5 per cent, and orthoclase, 3 per cent.

The thickness of the Gateway rhyolite is about 200 feet.
THE GATEWAY TUFF

The Gateway tuff is a thin formation with a very limited areal extent. It is best exposed at the intersection of Santa Rosalia Creek with Driftwood Creek and south for about 800 feet along Driftwood Creek. It is cut off on the south by the Driftwood Creek fault, and has been removed by erosion from the underlying Gateway rhyolite a short distance north of the junction of the creeks. It is overlain by the Driftwood Creek conglomerate.

The Gateway tuff is so fine-grained and dense that in the field it was first believed to be a flow. The later discovery of rounded, bedded pebbles within the formation proved it to be made up of clastic material. The rock is brown to brownish gray, and generally shows fairly well developed bedding.

The formation has a rather uniform thickness of about 20 feet over its limited outcrop.
THE DRIFTWOOD CREEK CONGLOMERATE

The Driftwood Creek conglomerate is exposed along Driftwood Creek from the Driftwood Creek fault north for about 1200 feet where a small east-west fault drops the formation down the few feet necessary to cut it off. A block of the formation is dropped below the creek bed on two small faults, but for the most part the northern half of the outcrop is above the creek. At the intersection of Santa Rosalia and Driftwood Creeks it is dropped down and forms the creek bed south to the Driftwood Creek fault.

The rock is gray-green and closely resembles the Gateway rhyolite in color. The discernible fragments are, for the most part, larger than those in other formations north of the Driftwood Creek fault. They are unstratified and the formation shows no bedding. Many boulders are from 1 to 2 feet in diameter and show the color and flow lines characteristic of the Gateway rhyolite. Because of this marked similarity it is thought that most of the material may have been derived from that rhyolite.

The weathered outcrop of the Driftwood Creek conglomerate is rough and broken, in contrast to the softer slopes and contours of the other conglomerates of the northern division. The sheer walls it forms along the east side of the creek are of a porous, or pock-marked, nature due to the weathering of the matrix. This has allowed the harder boulders and fragments to drop out of the face.

There is a slight thickening to the south, but the
average thickness of about 50 feet is fairly uniform over the short distance this formation is exposed.

**EAST RIDGE CONGLOMERATE**

The East Ridge conglomerate is named from the high ridge which forms the eastern rim of the Driftwood Creek valley. The ridge extends from the northeast corner of the map south, paralleling the creek, to the vicinity of topographic station 6. It is cut off there by a series of parallel east-west faults, one of which is the Driftwood Creek fault, and a number of east-west dikes and small intrusive bodies. The formation continues for an undetermined distance north of the map, but is cut off in the highly altered area at the south end of the ridge.

This volcanic conglomerate is made up of a series of interbedded tuffs and conglomerates. The lowest member is a chocolate-brown, dense tuff overlying the Driftwood Creek conglomerate as it appears on the east side of the creek. It is dropped down into the creek on a small fault and affords an excellent exposure about 500 feet north of the intersection of Santa Rosalia and Driftwood Creeks. It continues north until cut off on a north-south fault which drops the formation down against the Patrick conglomerate. Its thickness is 25 feet.

The second member of the East Ridge conglomerate is a
gray fragmental rock composed of small pebbles and silicified fragments in an arkosic matrix. It is identical in appearance to the Patrick conglomerate. Separation is made by thicknesses and associates. This member is only 110 feet thick whereas the Patrick conglomerate is about 400 feet thick. It is dropped down against the Patrick formation on a north-south fault which must have a minimum displacement of around 175 feet to achieve this relationship. The displacement is near the minimum however, as a small patch of the underlying tuff is visible at one place along the fault.

The third member is a light chocolate-colored tuff of such fineness and compaction that in the field it was taken to be an altered flow. The microscope, however, shows it to be composed of extremely fine-grained orthoclase and glass fragments with one tiny piece of quartz shown in the slide. This member is about 60 feet thick.

Overlying this tuff is another coarser conglomerate member consisting mainly of andesite pebbles up to an inch in diameter in an arkose matrix. This member is gray, but somewhat darker than the second member. It is well stratified, as are all the members, and about 75 feet thick.

The fifth member is another tuff very similar to the lower ones in appearance except that it weathers more buff than brown. It has a thickness of about 50 feet.

The top member of the formation, as mapped in this
area, is a coarser conglomerate with the amount of the matrix being high in proportion to pebbles. Both the matrix and pebbles are andesitic. Some pebbles are as much as 3 inches in diameter, though most are smaller. The pebbles are not too obvious because of their similarity to the matrix. Because of this, and the thick and not very prominent bedding, the observer is at first glance likely to take the rock for an andesite flow.

The color is dark grayish-brown somewhat similar to the conglomerate below and is about 330 feet thick. It caps the East Ridge and forms the back-slope (east) of the ridge.

All the members described in this formation exhibit fairly good bedding and rounding of the pebbles indicating some sorting and deposition in water. Their environment of deposition was no doubt very similar to the Patrick conglomerate.

ROCKS OF THE CENTRAL DIVISION

Rocks discussed under this heading are those found north of the Main fault and south of the Driftwood Creek fault. This includes an area east-west across the width of the map and a north-south extent of about 1500 feet.
The black basalt is exposed only in a limited area on the north side of the Main fault. The best exposure is about 1000 feet east of the water well in Driftwood Creek. The creek crosses the flow perpendicular to the strike cutting a shallow, narrow canyon through it. It dips eastward under the creek at about 25 degrees. On its western boundary it is brought up on a fault until it meets the Green andesite, which is normally about 110 feet above it stratigraphically. It is cut off on the south by the Main fault, and on the north by the Driftwood Creek fault and its associated parallel faults.

The fresh rock is black and fine-grained to aphanitic. In places, particularly just east along the creek from the water well, it is altered to a mottled reddish gray. It is exceedingly hard and tough and one is hard put to break it with a hammer. It is rather resistant to alteration. Two dikes cut it along the creek with practically no alteration shown. Dikes along its western margin have about the same effect. On the north side of the creek, however, in the highly altered area, it has succumbed to the alteration forces and has kept its individuality in only one or two places. Consequently, the contact lines as drawn on the map are somewhat problematical as is indicated by the question marks along them.
Under the microscope the rock is shown to be made up principally of labradorite feldspar \((\text{Ab}_5\text{An}_5)\) with feldspar laths up to 0.5 mm. in length set in a felty groundmass of minute feldspar laths. Augite forms about 10 per cent of the rock, some euhedral grains of which reach 1.2 mm. in length. Hornblende of about the same size forms 2 per cent of the slide, with a minor amount of calcite in the groundmass. Pyrite, which is unaltered and visible in the fresh hand-specimen, forms about 5 per cent.

The rock weathers into smooth, rounded forms as would be expected of a rock of its tough, homogeneous character.

The bottom of the flow is not known in this area, but it has an exposed thickness of about 150 feet. It is overlain by the Driftwood rhyolite.

**DRIFTWOOD RHYOLITE**

The Driftwood rhyolite overlies the Black basalt, but is exposed over an even smaller area due to its removal by erosion. It is best exposed in Driftwood Creek about 1500 feet east of the water well where the creek crosses it perpendicular to the strike forming a narrow, steep canyon cut into the hard flow. It is cut off on the south by the Main fault, and on the north by the Driftwood Creek fault and its accompanying parallel faults. In this area it is mostly covered by talus and the remainder is so altered
that it can be recognized only in places. The contacts as drawn on the map are, consequently, somewhat questionable. It dips east at about 28 degrees, which carries it under the creek within a relatively short distance. This dip would extend the flow over Black Ridge from which it has been eroded.

The Driftwood rhyolite is white to very light gray and aphanitic. It is highly silicified and, consequently, hard and tough. In the latter characteristic it resembles the underlying basalt. The lower 30 feet of the flow carries considerable pyrite which has weathered out on the exposed surfaces leaving pits and red blotches over the rock giving it an appearance not unlike red polkadots on white cloth. On a fresh break, however, the pyrite is unaltered. The upper part of the flow is slightly less silicified and carries less pyrite. It may be somewhat buff in color.

The Driftwood rhyolite is about 110 feet thick and is overlain by the Green andesite.

The Green andesite lies against the Main fault directly north of the mine and extends north until it is cut off on the Driftwood Creek fault, which runs in a generally east-west direction. It is cut off on the west by the Esperanza diorite intrusive, and on the east by a small north-south
fault. The base is not shown in this immediate vicinity.
The formation appears again, however, capping a small hill near the Los Angeles claim, which is east of the mine. At this point it is perhaps a half mile from the above outcrop, but is still on the north side of the Main fault. It does not appear south of the Main fault.

The eastern outcrop is cut off on the east by the Los Angeles fault and on the south by the Main fault. The northern boundary of the formation is in the highly altered area around topographic station 6 and is not distinct because of the faulting and excessive alteration. It is cut off there by the series of parallel faults.

In both areas of outcrop the formation caps hills, the top not being exposed, consequently, the thickness is not accurately known. It is underlain by the Driftwood rhyolite and has an exposed thickness of about 100 feet at the east outcrop with about 300 feet exposed at the west outcrop.

The flow is dense, aphanitic, and fairly uniform in its olive-green color, though it may have local areas of greenish to bluish gray. On the weathered surface it may be stained chocolate brown or black. Near intrusives it usually alters to white or buff. This phenomenon is well shown along the Main fault near its intersection with the Mine fault.

It weathers into very smooth, rounded contours, and while it yields readily to the hammer, in fact can often be broken by the hands. It generally breaks with a conchoidal
fracture and regardless of the shape of the fragment one starts breaking, he usually finishes with a more or less round one.

The Green andesite rarely shows any kind of inherent structure and dip and strike are usually unobtainable.

Under the microscope the rock is shown to be very uniform in grain size, with the largest feldspar laths being 0.5 mm. in size. The average size of the laths is about 0.15 mm. Andesine $Ab_{60}An_{40}$ covers about 48 per cent of the slide. Orthoclase 5 per cent, devitrifying glass makes up about 17 per cent, limonite 10 per cent, and serpentine 20 per cent forms the remainder. The serpentine supplies the green color which is characteristic of the formation.

ROCKS OF THE SOUTHERN DIVISION

The rocks described under this heading are found south of the Main fault.

FOX CREEK ANDESITE

The Fox Creek andesite is the lowest formation of the area south of the Main fault and is found in Fox Creek about one-half mile south of the camp. The road to Arizpe does not cross this formation, but it can be seen from the road as one goes down the last hill into the creek bed. At this
point it presents a sheer cliff which rises up out of the bed gravel on the west side of the creek. The cliff here is not formed by the creek cutting into the formation, which is the first impression one receives, but is the west side of the Fox Creek fault which enters Fox Creek at this point. This cliff is the formation's most eastern outcrop as it does not appear east of the Fox Creek fault.

The formation's area of outcrop is limited in the mapped area, though it is known to continue off the map to the west for at least one quarter mile. The dip, which is 25 degrees to the north, carries it quickly into the hill on the north side of the creek, while the up-dip takes it into Fox Hill which is on the south side of the creek. Its only exposure is, therefore, on the walls of the creek west of the Fox Creek fault.

The bottom of the flow is not known. It has an exposed thickness of about 50 feet and is overlain by the Fox Creek conglomerate.

The Fox Creek andesite is medium green and aphanitic. It is dense and massive with no flow structure shown. It is tough, and usually breaks with a conchoidal fracture. It does not yield readily to the hammer.

It weathers into rounded forms on the top of the flow and gives smooth, sheer walls where it is exposed on both sides of Fox Creek where the stream is entrenched in it.
Under the microscope the rock shows alteration to such an extent that determination of the feldspar is questionable, but is probably andesine. It forms about 45 per cent of the rock. Serpentine from the alteration of an undetermined ferro-magnesian mineral, or minerals, forms about 50 per cent of the rock. Secondary calcite makes up the remaining 5 per cent of the section. Sericite is formed from alteration of the feldspars.

**FOX CREEK CONGLOMERATE**

The Fox Creek conglomerate overlies the Fox Creek andesite and is exposed in the creek of the same name. Its areal extent on the area mapped is limited on the east by the Fox Creek fault, but it continues to the west for an undetermined distance. The dip of the formation is about 25 degrees north as it crosses Fox Creek. The dip carries it below surface on the north side of the creek and the up-dip carries it into the side of Fox Hill on the south side of the creek. It has been cut completely through by the creek and presents almost sheer walls on either side of the creek.

It is a hard, well-cemented formation averaging about 30 feet in thickness. In this area it is medium green to reddish in its over-all appearance.

This volcanic conglomerate is composed of clastic material derived both from the underlying Fox Creek andesite
and more distant sources. The material is all of igneous origin and the pebbles range in size from that of a small marble to boulders 18 inches in diameter. The pebbles are fairly well rounded and are thickly set in the matrix, which is arkosic in character having been derived from eroded volcanic material. The formation shows no stratification.

ESPERANZA DACITE

The Esperanza dacite overlies the Fox Creek conglomerate and is exposed on both sides of the creek west of the Fox Creek fault, as is the conglomerate. The outstanding feature of this flow is its stage of alteration. All the minerals have been so altered as to present an exceedingly nondescript, clayey appearance to the observer. A few of the feldspar laths are still discernible with the hand lens, but most of the rock is just an amorphous mass megascopically.

It is light green to almost white and is soft and spongy to the hammer. Its thickness is about 25 feet.

This rock, when viewed through the microscope, is unique for this area. The groundmass is composed of quartz and feldspar grains of remarkably uniform size and distribution, being about 0.01 mm. in diameter. About 15 per cent of the feldspars reach 0.5 mm. in size.
The feldspar is almost completely altered to kaolin, with only the shadows of the twins showing through the least altered laths. These altered laths, evenly distributed among the unaltered quartz grains of equal size give the section a most unusual appearance.

Feldspar (andesine) forms about 50 per cent of the section, quartz about 48 per cent, with secondary calcite making up the remainder.

**SANTA ROSALIA ANDESITE**

The Santa Rosalia andesite covers a considerable portion of the south part of the area mapped and continues east, west, and south for an unknown distance. Its northern boundary is at the Mine fault where it is cut off by the fault and the Esperanza intrusive. From the Mine fault it continues south across Fox Creek and caps Fox Hill. The outcrop swings east along the north side of Fox Creek, as well as extending south across the creek, but in this area is cut off on the north by a fault which runs generally east-west across the area.

The flow overlies the Esperanza dacite and is overlain by the Santa Rosalia fragmentals. It is andesitic in character and shows excellent flow structure throughout its lateral and vertical extent. It has split along the flow lines and presents a bedded appearance, with the individual
"beds" being from 1" to 4" in thickness. In places there is banding within the layers.

The upper part of the Santa Rosalia andesite is generally brownish-gray, while the lower part assumes a reddish tint, and the layers are generally thicker with the banding not apparent. The feldspar laths tend to become slightly larger, as a whole, and present a more felty or matted appearance.

While the contact of this flow with both the underlying and overlying formations is known, the top and bottom are not in the same section but have a fault separating them that makes accurate determination of the thickness impossible. There is an exposed thickness of about 700 feet.

Under the microscope the lower, or reddish, part of the flow shows less alteration than the upper part, but alteration is extensive nevertheless. The rock is made up of 80 per cent andesine in a glassy groundmass. The laths range up to 1.2 mm. in size. Some completely altered ferromagnesian minerals have formed serpentine for a total of 1 per cent and iron ore in the amount of 3 per cent, the latter accounting for the reddish color of the lower part of the formation. Secondary calcite is present in minor amount but quartz is notably absent. The feldspars are much sericitized but less kaolinized than in the upper part of the formation.
The upper, or gray, part of the formation shows iron ore in the amount of less than 1 per cent, which accounts for the lack of red color in the outcrops. Ferro-magnesian minerals are notably less abundant, but a few grains are present. One altered biotite measuring 1.2 mm. was noted. Quartz makes up about 20 per cent of the section but is principally secondary. Andesine \( (\text{Ab}_{60}\text{An}_{40}) \) makes up the remainder of the rock. The feldspar has less sericite than the lower part of the formation but is highly kaolinized. About 50 per cent of the feldspar is felty groundmass with phenocrysts up to 2.2 mm. forming the remainder.

**SANTA ROSALIA CONGLOMERATE**

All of the Santa Rosalia conglomerate that is known occurs south of the Main fault, and all but a few scattered patches occurs south of the Mine fault. The few patches were left along the edges of the Esperanza diorite intrusive which lies between the two faults. From this northern boundary the formation swings south and east so that the outcrop forms an open arc on the surface. The structure is that of a syncline plunging northeast. The Los Angeles fault bounds the formation on the east. The Santa Rosalia conglomerate overlies the Santa Rosalia andesite, and, in turn, is overlain by the Ludden andesite. Its dip is consistently easterly, but approaches north on the east.
limb of the syncline. The dip averages about 45 degrees.

The Santa Rosalia conglomerate is composed of well-stratified beds of pebbles and boulders alternating with thinner beds of arkose which contain minor amounts of fairly well-rounded quartz grains. Most of the fragments are andesite, but some are of intrusive rocks. They range in size from one-fifth inch to 12 inches in diameter and are fairly well rounded. The ratio of beds of pebbles to beds of arkose is possibly 20 to 1. Arkose beds range from 2 inches to 5 feet, and pebble beds vary between 1 foot and 20 feet in thickness. The total thickness of the formation is about 1050 feet.

Near the top of the formation the pebbles become, as a whole, smaller and more uniform in size. They rarely exceed 4 inches in diameter. They are more silicious and are usually very well rounded, resembling river gravel. The color of these beds is a vivid red as contrasted to the purple shades of the lower part of the formation.

Most of the formation, where unaltered, is characteristically purple to red in color with some gray and buff beds. The outcrop forms lowlands and soft slopes of a dominant purple hue. The formation is cut by many dikes and is usually highly altered by them. This altered facies is buff to white and the bedding planes are usually destroyed so that it gives the appearance of being a much altered andesite flow. A careful search will generally reveal some
small silicious pebbles that have not been altered and it is upon this criterion that the observer must often rely.

LUDDEN ANDESITE

The Ludden andesite overlies the Santa Rosalia fragmentals and is capped by the Los Angeles fragmental formation. It is present throughout the area covered by the Santa Rosalia fragmentals, but is on the inside of the synclinal trough so that the length of the outcrop is somewhat shorter. The best exposure is on Ludden Ridge. Here the eastward dipping flow forms a hog-back ridge with the fragmentals forming a smooth slope underneath.

The flow is gray and is from 50 to 200 feet thick. It is aphanitic, but porous, having many vesicules some of which are three-quarter inch in length. Some of the vesicules are filled with calcite. The tiny white grains, which at first glance appear to be feldspar laths, are secondary calcite. Calcite stringers, visible upon close examination, are common. Almost the entire surface of the rock seems to effervesce vigorously when acid is applied.

Under the microscope the rock shows a composition of about 78 per cent oligoclase (?) as an extremely fine-grained, felty mass of laths. The feldspar has been almost completely kaolinized rendering identification somewhat questionable. Calcite, as stringers and vesicule-filling,
forms about 20 per cent of the slide. Iron ore, from the alteration of some ferro-magnesian mineral (biotite?) having parallel extinction but which is too altered to positively identify, forms the remaining 2 per cent of the slide.

The contact of this flow with the underlying fragmentals is fairly even and regular, but its upper contact with the overlying fragmentals is rough and uneven with the resulting thickness being quite variable. This is taken to indicate that the overlying fragmental material was laid down on an unevenly eroded surface. Much of the upper contact is obscured by talus from the overlying fragmentals and in many places the entire formation is covered. The flow is thickest on the north and thins rapidly toward the southeast.

LOS ANGELES CONGLOMERATE

The Los Angeles conglomerate overlies the Ludden andesite and is similar to the Santa Rosalia conglomerate which underlies it. The lower part of the formation, as it occurs around No. 4 triangulation station, is composed principally of andesite boulders up to 18 inches in diameter cemented in an arkosic matrix. This material has been somewhat silicified so that it stands up much better than the Santa Rosalia conglomerate beds and forms the top of
hill which has rather precipitous slopes. The silicified beds have been considerably fractured and large blocks of the material, still cemented firmly together, form a heavy talus on the east side of the hill.

The large boulders grade upward into smaller material and near the top the pebbles are so few that one is likely to have to search for them. Part of this non-appearence of pebbles us due to extreme alteration of the beds along dikes. However, in the relatively unaltered portions the diminution in size of the pebbles is very noticeable.

The Los Angeles conglomerate is areally confined to the angle between the Main fault and the Los Angeles fault. The Main fault cuts it off on the north and the Los Angeles fault, which intersects the Main fault at an angle of about 80 degrees, cuts it off on the east. Fragmental beds are also present on the east side of the Los Angeles fault but they are believed to be of another series.

The formation is about 500 feet thick.

LOS ANGELES DACITE

The Los Angeles dacite is on the east side of the Los Angeles fault and caps the hill upon which Triangulation station 7 stands. The flow is out of the area the writer intended to map, but was mapped, because of its connection with the Los Angeles fault and because of its peculiar appearance.
It is aphanitic, green, and though considerably altered is still hard and resistant to the hammer. This is probably due to a considerable quartz content in the matrix. The most unusual feature of the rock, however, is the presence of irregular dark green blotches of serpentine scattered through the rock, ranging in size from ¼-inch to 1½ inches in diameter. Most of the blotches contain visible iron ore. The surface is pitted where the ferro-magnesian minerals have weathered out.

Under the microscope the section shows highly altered oligoclase phenocrysts up to 2.4 mm. in size set in an extremely fine-grained groundmass of quartz, feldspar laths and calcite. The high power of the microscope is needed to determine the minerals of the groundmass. Phenocrysts occupy about 5 per cent of the section. A few scattered grains of quartz measure up to 0.2 mm.

The slide, as a whole, shows considerable kaolinization and sericitization. In addition, the feldspar phenocrysts have been in part replaced by epidote (?) which has altered to serpentine. This replacement is usually concentrated in the center of the feldspar and may or may not extend outward to cover the entire lath. One such lath shows sericite surrounded by serpentine, both being contained within the boundary of the feldspar. Scattered grains and stringers of calcite form about 3 per cent of the slide.
The flow is very limited in areal extent, being found only on the top of No. 7 hill. It is cut off on the west by the Los Angeles fault, which dragged a long narrow block of the flow down into the fault zone. Its thickness is about 200 feet.

**Age Relations**

Lavas have been studied in but a few places in north-eastern Sonora. The deposits at El Tigre, Nacozari and Cananea have been assigned to the early Tertiary. King tentatively assigned similar lavas from east-central Sonora.


and western Chihuahua to the early Tertiary.


In view of the foregoing information it seems likely that the flows and conglomerates of the Central and Southern divisions in this area are also of Tertiary age. However, it is not possible to assign them to a certain age at this time.
The Esperanza diorite lies along the west edge of the area mapped. Its easternmost outcrop is between Main and Mine faults. Its northernmost expression is as dikes crossing Santa Rosalia Creek about one half mile north of Main fault. It continues for an unknown distance to the west of the mapped area.

The Esperanza diorite is younger than most of the faults in the area. It appears unbroken on both sides of the Main and Driftwood Creek faults, but minor movements along the Mine fault subsequent to intrusion have fractured the igneous body. Some mineralization is localized along the break.

In Santa Rosalia, where the diorite intrudes the Patrick conglomerate in the form of narrow dikes, the intrusive is gray, fine to medium-grained, and relatively fresh in appearance. The microscope shows that it is composed of 80 per cent andesine feldspar (AB̂60An̂40) which is considerably kaolinized. Augite, part of which is altered to epidote, makes up about 15 per cent of the rock. Biotite, also partly altered to epidote, forms 1 per cent. The remainder of the rock is composed of quartz, 3 per cent; iron ore, 2 per cent, and some secondary calcite. Apatite
occurs in minor amount.

The Esperanza diorite near Mine fault is considerably different in appearance from that in the Santa Rosalia Creek dikes. However, microscopic examination shows it to be similar in composition. Near the Mine fault it does not have the fresh, crystalline appearance or the gray color characteristic of the northern outcrops, but is dull gray-green with only buff to yellow-orange feldspar laths remaining recognizable in hand-specimen. The laths are up to 2 mm. in size, giving the rock a porphyritic texture.

The microscope shows the facies near Mine fault to be slightly more acidic than the Santa Rosalia Creek facies. The andesine is \( \text{Ab}_{70}\text{An}_{30} \) and is more kaolinized than that in the northern facies. It forms about 70 per cent of the rock. Quartz makes up about 15 per cent, with perhaps 5 per cent of it in the form of secondary stringers. Augite and biotite is altered to epidote, which is responsible for the dull green groundmass. There is a small amount of apatite.

The Esperanza diorite intrusive is believed to be the source of the mineralizing solutions which formed the deposits of gold, silver, lead, and zinc which are along its contact with the conglomerate beds in the Mine fault zone.

The andesite porphyry dike material is believed to be a differentiate, which came up along zones of weakness after the main mass of the diorite had solidified.
Andesite Porphyry

The andesite porphyry occurs as dikes whose widths range from 4 to 700 feet. Occurrence is not limited to any of the three divisions of the area. The dikes, with few exceptions, strike generally east-west paralleling the large faults. The greatest number is in the Central and Southern divisions, with relatively few in the Northern. The dikes are numerous in the immediate vicinity of the mine and occur in swarms in the area around triangulation station 6.

The altering effect of the dikes upon the country rock is governed by the character of the rock intruded. In many places the conglomerates have lost all identifying characteristics, such as color, bedding and fragmental nature, for hundreds of feet around the intrusive. On the south end of East Ridge the flows, as well as the fragmentals, have been reduced to a nondescript, red and white, spongy mass of altered rock.

The other extreme is shown in Driftwood Creek where two parallel dikes, each about 20 feet wide, spaced 40 feet apart, cut the Black basalt without appreciable effect.

In general, the dikes have considerably altered the fragmental rocks, but have altered the flows to a less extent.
The andesite porphyry is gray to buff, depending upon its state of alteration. In the gray variety, black hornblende phenocrysts up to 5/8-inch in length are abundant. In the buff porphyry the phenocrysts are green. Feldspar laths in the gray facies are distinct in the hand-specimen and measure up to 2 mm., while those in the buff are usually not visible.

Microscopic examination shows the rock to be composed principally of andesine \((\text{Ab}_{50}\text{An}_{50})\). The groundmass of felty andesine laths shows flow structure in the swirling of laths around the phenocrysts. Phenocrysts, up to 2 mm. in length form about 5 per cent of the total. Andesine in the groundmass forms about 79 per cent. Hornblende (on the thin section) up to 2 mm. makes up 15 per cent. The hornblende is altered around the edges to iron ore, which forms 1 per cent. There is a minor amount of calcite. There is some kaolinization and sericitization of the feldspars.
Rhyolite Porphyry

Rhyolite porphyry has been found in only one dike. This dike is in the Northern division and, as shown on Plate 1, forms the crest of a long ridge which extends off the west edge of the mapped area 1000 feet south of the limestone contact.

This porphyry has the same appearance as the dikes coming off from the San Francisco intrusive a few miles to the north. The dike is the only outcrop of the San Francisco intrusive in the mapped area. The main body of the intrusive is about one mile to the west.

The presence of this outlying dike of San Francisco intrusive leads to the speculation as to whether the entire mapped area is underlain by the San Francisco granitic mass, with the Esperanza diorite and the andesite porphyry dikes being more basic differentiates of that main body.

The rhyolite porphyry is light purplish to light brown. It appears aphanitic on a rough surface, but feldspar phenocrysts are visible on a sawed face. Most of the biotite is weathered out leaving a porous and pock-marked surface, but some phenocrysts measuring up to one fourth inch in size remain. In thicker dikes, occurring out of the mapped area, biotite books are as much as half an inch in diameter.

Under the microscope the biotite appears to form about 5 per cent of the slide. Orthoclase (no plagioclase noted)
phenocrysts up to 3.4 mm. in length also make up about 5 per cent. Quartz, in visible grains, forms 3 per cent but more probably occurs in the groundmass. The groundmass, which is mostly glassy, forms the remaining 87 per cent of the slide. Minor amounts of calcite are present in the groundmass.

STRUCTURE

The structure in the Santa Rosalia area seems to follow a fairly simple and regular pattern. The major trend is east-west. This trend is represented by the Main and Driftwood Creek faults as well as most of the smaller breaks. A secondary, though important, trend is north-northwest. This is represented by the Los Angeles and Fox Creek faults and a number of smaller breaks.

The regional dip in the mapped area, is toward the east at an average of about 30 degrees. A continuous ridge of limestone which conforms to the regional dip, begins at the north edge of the mapped area and is cut off about 10 miles north near the San Antonio Ranch. The limestones seem to have no preferred direction of dip north of the end of the limestone ridge.

The San Francisco intrusive forms a high ridge west of the limestone ridge and parallels it almost the entire distance. The distance between the ridges is probably, on
the average, a mile or less. This relationship indicates that at some time after the deposition of Lower Cretaceous sediments, probably during the Laramide Revolution, the San Francisco body intruded and uplifted the sediments resulting in the establishing of a fairly uniform dip away from the intrusive along its entire front.

The north-south limestone ridge ends near the San Antonio Ranch in an almost sheer cliff. Examination would undoubtedly show an east-west fault along the cliff which was caused by the north side, which did not have the uplifting effect of the intrusive, breaking off and remaining behind as the south side was raised. This type of differential adjustment is probably the cause of the east-west faulting in the mapped area.

The Northern division contains one dike of material similar to that in the San Francisco intrusive, and the main body of this rock is about one mile to the west. It is possible that much of the area mapped may be underlain by this intrusive. In any event, the Northern division was uplifted more, probably because it was closer to the intrusive mass, than the Central and Southern division, in which the limestone beds are not exposed.

In any area undergoing differential elevation, the difference must be adjusted either by folding or faulting. The strike of the adjusting structures is necessarily more or less perpendicular to the strike of the tilting body.
In the Santa Rosalia area the tilting body is the San Francisco intrusive. The displacement of the beds by it was apparently of such magnitude that compensation could not be made by folding, and a series of east-west faults resulted. Two of these (the Main and Driftwood Creek faults) have throws measuring some thousands of feet. The exact amount of the movement, either vertical or horizontal, can be determined only by finding the unfaulted formations as they appear above the limestone. Presumably these beds lie east of the limestone outcrop and north of the Driftwood Creek fault.

There are a number of small faults with throws up to 50 feet in the Northern division. Most of them are generally east-west. An exception is the long north-south fault along which the gray conglomerate member of the East Ridge formation was dropped down against the Patrick conglomerate. This fault starts in the highly altered area east of Driftwood Creek and continues northward beyond the area studied. Its displacement increases to the north. At the northern edge of the mapped area, this fault has brought the gray conglomerate member of the East Ridge formation down against the Mural limestone, which gives a displacement of approximately 700 feet. Along the middle part of the mapped section of the fault the gray conglomerate member of the East Ridge formation is against the Patrick conglomerate, which indicates a vertical displacement of about 300 feet.
In the altered area around triangulation station No. 6 there are many faults and swarms of dikes, most of which strike generally east-west. The alteration is so great that positive identification of various formations in this vicinity is not possible at the present time. The amount of displacement along the faults and the relationship of the formations are unknown. The mapped contacts are problematical, as indicated by question marks along them.

In the highly altered area all formations have lost their individuality as to color, texture, and general appearance. The area, which is on the south end of East Ridge, is brilliant red spotted with white in more leached parts. The rocks are soft and spongy, as is characteristic of highly altered flows and conglomerates. Formations on the northern side can be traced into this area, but they do not reappear south of it. The same is true of the southern formations. They do not reappear north of it.

The summit of the south end of East Ridge is formed by a zone of silicification. Talus from the softer parts covers most of the slopes.

The Driftwood Creek fault runs through this altered area. It is the writer's belief, however, that all the displacement does not occur on it. There is another break north of this fault which may also have a considerable throw, and the swarm of parallel dikes cutting the area
almost certainly fill fractures and faults of varying dimensions. The displacement necessary for the disappearance of the northern formations and the appearance of an entirely new series appears to be due to the cumulative throw of a series of parallel faults rather than of one large one.

On the west side of Driftwood Creek the throw is confined to the Driftwood Creek fault. Its presence is determined more by inference than by ability to see the break for much of it is filled by dike material. Most of the rest of it is covered by talus. The fault is exposed in Driftwood Creek, however.

The Driftwood Creek fault is a curving fault closely paralleling the Main fault, which lies some 1500 feet to the south. The dip at the creek is about 85 degrees to the south. The throw is not known, but must necessarily be in excess of a thousand feet.

The formations of the Northern division do not appear south of the Driftwood Creek fault.

The Main fault is a normal fault with a stratigraphic throw known to be more than 600 feet and is probably much greater. It separates the Central and Southern divisions. Its strike across most of the area is N 70 W with the dip ranging from vertical to 72 degrees to the south. At the west edge of the map the fault curves to the south until the strike is N 75 E and the dip is 86 degrees to the south.
At the west it is cut off by the Esperanza diorite intrusive. It is cut off on the east by the Los Angeles fault which brings in a new section. This section, except for the Los Angeles flow, has not been mapped. A dike east of the Los Angeles fault continues along the general strike of the Main fault but no displacement along it was noted.

The Mine fault is one of little displacement. The Santa Rosalia conglomerate occurs on both sides of it, but almost all the conglomerate between the Main and Mine faults has been displaced by the Esperanza diorite. There has been some movement on the Mine fault since the intrusion of the diorite, however, as can be seen in the creek which bounds the west edge of the area. Some vein material is in the break, indicating that the mineralization, or part of it, is post-faulting in the diorite. Evidence of post-mineralization movement on the Mine fault is indicated by the 200 foot westward offset of the silicified zone of the Fox Creek fault along the Mine fault.

The Mine fault diverges from the Main fault at an angle of about 30 degrees and continues, with a strike of about N 70 E, into the intrusive diorite. The dip averages about 80 degrees to the south.

The Fox Creek fault is a long, curving fault which is cut off on the north by the Main fault. From a southwest strike at the Main fault, it curves southward and leaves the area in a southeast direction. It is one of the smaller
faults, having a displacement of between 110 and 350 feet.

The fault cuts the Esperanza diorite tongue between the Main and Mine faults, but is offset to the west about 200 feet on the Mine fault. In the intrusive it is marked by an area of silicification which, being much more resistant to erosion than the intrusive, stands about 50 feet above the diorite like a wall extending from the Main to the Mine fault. This zone of silicification (see Fig. 2) forms Santa Rosalia Peak.

From the Mine fault offset the Fox Creek fault continues to the creek that forms the western boundary of the mapped area. Here the silicification ends and does not reappear for a thousand feet along the fault. Its next appearance is where the fault crosses a saddle just north of Fox Creek. There is no silicification along the fault south of this saddle.

This fault, too, is pre-mineralization in age since the ore mineralization probably accompanied the silicification of the fault zone. Slickensides on the silicified material indicate, however, that some movement occurred at a later time. Some dikes cross this fault, indicating igneous activity after its establishment.

The best exposure of the Fox Creek fault is in Fox Creek. Here it brings the Fox Creek andesite against the Santa Rosalia andesite in a knife-edge contact. Since the Fox Creek flow is much more resistant to erosion than the
Santa Rosalia andesite, the creek has cut away the andesite leaving a sheer wall, which is the fault plane, of the Fox Creek flow. Just south of this exposure the fault disappears beneath the talus of the hill and is not seen again in this area.

The dip of the fault at its northern end is about 70 degrees to the east. At the exposure in Fox Creek it is vertical.

An unnamed fault of major proportions takes off from the Fox Creek fault about 1000 feet south of its intersection with the Mine fault and continues southeast across the area to the vicinity of a large east-west dike. It crosses the creek here and runs along the north side of a hill where it is lost underneath the talus. The writer is inclined to believe that the displacement south of the wash is small and that probably the major displacement in this area is along a break that has been filled by the dike. The Santa Rosalia fragmentals are considerably thicker in the southeast part of the map and this could be the result of the fault repeating part of the thickness.

This fault, together with the Fox Creek fault, bounds a wedge-shaped block which has been downfaulted. This action has brought the Santa Rosalia fragmentals down so that they reappear below the andesite. Their outcrops are scattered remnants for the most part, which have been left by erosion, surrounded by the andesite. In the creek north
of the well the faulting has been extremely complex and some of the fragmental beds have been left standing on end. This complex is near the large fault and is apparently the result of it, having no particular bearing on the structure in general.

The displacement on the fault, in order to bring the Santa Rosalia fragmentals down below the andesite, must be on the order of 700 feet.

The Los Angeles fault trends generally north-south along the eastern boundary of the area, cutting off the Los Angeles fragmentals, the Ludden andesite, the Green andesite, and the Driftwood rhyolite. The Santa Rosalia fragmentals also end on this fault.

The fault is probably normal but the displacement is not known since the Los Angeles dacite does not appear elsewhere in the area. It is believed to be in excess of 1000 feet however. That it is later than the Main fault is indicated by its displacement of formations appearing on both sides of the Main fault.

The faulting is a zone rather than a single fault. On the south side of the Main fault a long narrow block of the Los Angeles dacite is dragged down into the fault zone. On the north side of the Main fault the zone is not prominent but is probably present.

The Los Angeles fault is well marked by the topography south of the Main fault. It forms a gap in the ridge which
it crosses just south of the Main fault, and a creek follows the zone southward. The terrain on the east of the fault is low and rolling, while that on the west is high and rugged. Both sides are fragmental, but those on the east are, for the most part, made up of smaller pebbles and finer material more poorly consolidated than those on the west.

ORE DEPOSITS

History of Santa Rosalia Mine

The Santa Rosalia Mine is an "antigua", or old Spanish working. It was operated by the Spaniards until they were driven from the country by the Yaqui Indians. They started working the vein from the surface and continued down to near water level, which is about 350 feet below the outcrop at this point. The open cut at the surface and some of the stopes are still accessible.

After the Spaniards were driven out, the property lay idle until about 1894 when it was taken up by an American company organized in San Francisco. This company operated successfully for about 3 years and then became involved in legal difficulties among the owners. After a period of idleness the property was taken over by a company from Calumet, Michigan. This company operated for a time when
it too had internal trouble, as well as difficulties with the then unstable governments of Mexico, and ceased operation in 1912. The mine has not been worked since.

The present company is a rejuvenation of the old Michigan company. It has built a 100-ton mill, the first one at the property, and expects to begin operations in 1948. Previous companies shipped hand-sorted ore, most of which ran well over $1000 per ton in gold and silver. The property under the various owners, is reputed to have produced several million dollars in gold and silver.


MINERALIZATION AND GOVERNING STRUCTURES

The ore at Santa Rosalia mine occurs in the Mine fault. This fault has been briefly described under STRUCTURE, but a more detailed description will be given here.

The Mine fault is a normal fault, dipping south at an average of 80 degrees, with a horizontal displacement of about 200 feet. Its vertical displacement is not known, but is believed to be small. Santa Rosalia conglomerate occurs on both sides of it. It is a break resulting from major movement along the Main fault from which it diverges.
westward at an angle of about 30 degrees.

After the principal faulting action had subsided the Esperanza diorite intruded a wedge into the angle formed by the Main and Mine faults. This wedge is the quartz-diorite porphyry facies. It displaced nearly all of the Santa Rosalia conglomerate into which it was intruded.

Subsequent to the solidification of the diorite porphyry, movement on the Fox Creek fault fractured the porphyry in a generally north-south direction. This zone of weakness was also probably developed as a result of the movement on the Main fault. After the fracture zone of Fox Creek fault had been established, mineralizing solutions from the diorite magma, as yet unsolidified at depth, came up along the Fox Creek fault and into the Mine fault. Mineralization action along Fox Creek fault, as it cuts the diorite porphyry, is, superficially at least, principally silicification. Subsequent erosion has left this resistant area above the surrounding unsilicified diorite (see Fig. 2).

While the action on the Fox Creek fault was one of silicification, the mineralization along the intersecting Mine fault is that of fissure-filling by quartz and sulphides, with which the gold and silver is associated. The area of most extensive veining by the quartz is from the intersection with the Fox Creek fault eastward for about 1000 feet along the strike of the fault toward its intersection with the Main fault. The vein material is present
throughout the entire length of the Mine fault, which is about 1800 feet between the Fox Creek and Main faults, but is not as well developed at the east end.

After the silicifying action had ceased on the Fox Creek fault, movement on the Mine fault moved the block south of the Mine fault about 200 feet west. This action fractured the vein quartz in the mine, as is shown in the back of the east drift of the adit level. Other veins in the mine show no fracturing and are taken to have been deposited later than the last movement on the Mine fault.

The open cut along the vein begins at the Fox Creek silicified zone in the diorite and extends along the Mine fault eastward for about 700 feet. The width of the cut is variable, as the ancients mined to the assay walls of the material that was ore at that time. In places the width of the cut is 50 feet, in others 10 feet, and in two or three places the cut stops and starts again after an interval of a few feet. North of the open cut some stringer veins of quartz remain. At one place this material is about 30 feet wide, consisting of parallel quartz stringers 1 inch to 3 inches wide separated by from 3 to 12 inches of country rock. This quartz shows evidence of having contained pyrite but all sulphide minerals have been leached from the outcrop.

The depth of the original open cut is unknown since it has long been partially filled by talus from the steep
Santa Rosalia Peak upon whose slope it is cut.

At the east end of the cut the work goes underground and a stope stands open from the surface to the adit level which is about 250 feet below. Some of the stalls and "chicken ladders" used by the Spaniards are still in the stope and are in a remarkable state of preservation. Some assays from the stope walls showed a value of $45 in gold and silver.

The nature of the fracturing is better revealed underground than on the surface. The fault, in spite of its small displacement, has, where the east adit-level drift crosses it, 10 inches of gouge. Where the adit intersects it, however, there is no gouge. On both sides of the fault are innumerable parallel fractures, none of which contain gouge, having very little if any displacement. Some of the fractures are filled with white to gray fine-grained quartz. Others are only partially filled with quartz with the remaining opening filled, or partially filled, with sulphides of lead and iron. Some sphalerite was noted on the 100-foot level.

A fault which strikes almost at right angles to the
Mine fault occurs at the winze on the east drift. This apparently localized a small amount of the ore as a winze and a raise have been put in against it. Ore in the winze is reported to have assayed $90 per ton.

Very little visible sulphide remains on the levels above the water level, having been successively stripped by three different operators. One stringer above the adit level, which has been left as too low grade to mine, assayed $16 in gold and silver across 4 feet. On the 100-foot level mining was discontinued in a drift with some 30 inches of sulphides in the face which assayed $11 in gold and silver with a high percentage of lead. Ore at the water level in the shaft assayed $30 in gold with an appreciable amount of silver.

The high-grade ore, if any, that was present in the upper workings was removed by the early Spaniards of which there are no records. The ore below the water level was protected by the water until the coming of the Americans. From the 200- to the 300-foot levels ore was extracted which yielded $2000 per ton on the $20 per ounce base. This is again under water and the nature of the deposits cannot be determined, but in all probability are of the same character as those remaining above. The ore minerals are argentiferous galena, gold-bearing pyrite, with minor amounts of chalcopyrite and sphalerite in a quartz gangue. Free gold is present but not common.
The ground west of the adit toward the intersection of the Mine fault with the Fox Creek fault is more highly fractured than that to the east and is caved and inaccessible.

The Mine fault is crossed by dikes which are later than the faulting or the mineralization in the mine area. One such intrusion is cut by the east adit-level drift just east of the winze (see Plate 2). This dike came up along the fault and cut across it into the footwall. It presented a problem to earlier operators which resulted in their driving a cross-cut some 40 feet back into the footwall, then east along a parallel fracture. They followed this fracture for a considerable distance before coming back to the original break.

The fracturing and alteration at the east end of the workings leave some question as to which break is the one upon which the drift was started, as indicated by the level map (Plate 2). The vein material at this point on the surface is narrow and less shows underground.

A tunnel which was driven into the Main fault zone just east of the intersection of the Mine and Main faults shows the ground to be cut by a great number of more or less parallel east-west fractures which resulted principally from movement on the Mine fault. The marked parallelism of the dikes in the area indicate that nearly all the fracturing was in an east-west direction.
The wall rock is highly fractured and considerably altered in most places. Kaolinization is prominent with a lesser development of sericite. The wall rock is liberally sprinkled with pyrite.

Where the ore is still present along permeable fractures, it is porous and rusty from the leaching of the pyrite. The galena beneath the surface is unaltered. Where the circulation of water is restricted both the galena and pyrite are unaltered.

The pyrite, where in contact with abundant oxygen as in fractures allowing free circulation of waters, has broken down forming sulphuric acid. This oxidation of the pyrite has been carried to such a degree that the mine water is of such acid content as to be injurious to the skin. Ordinary pumping equipment cannot handle water of its acidity, and the company was obliged to install acid-resistant pumps.

A curious phenomenon resulting from the oxidation of the pyrite is found in the creek that forms the west boundary of the map where the Mine fault, and its accompanying fractures, cross the creek. Here the sulphate-bearing waters are coming to the surface after percolating through the mineralized fractures and are forming gypsum deposits along the bank of the creek. Some of the material is in the form of well-developed crystals showing the swallow-tail type of twinning. The size of the largest crystals is perhaps 4\(\frac{1}{2}\) inches in length.
While, as stated before, the mineralization at the mine appears to have been before the intrusion of the dikes, one east-west dike about 400 feet west of the Los Angeles fault is cut by many parallel veins of quartz. The dike is in the Los Angeles conglomerate and parallels the Main fault. The conglomerate on the south side of the dike, which forms a ridge, is altered to a characterless mass of red, white, and yellow material. It is less altered on the north side and retains much of its original appearance.

Some pitting and tunneling has been done on the dike, most of it apparently by natives, but no sulphides such as occur in the mine were noted. A sample taken from these veins was reported to have assayed $17 in gold, however.

**ZONES FAVORABLE TO ORE DEPOSITION**

Stopped areas indicate the ore occurred in tabular bodies along the steeply-dipping Mine fault. In the upper levels the quartz veins show no preference between the Esperanza diorite on the north side of the fault and the Santa Rosalia conglomerate on the south side. Both rocks are fractured and afford easy access to solutions.

A Mr. Whitesides, engineer for the company in 1912, stated in a letter: "the best ore is found in the breccia".
He was speaking of the lower levels of the mine and probably referred to the Santa Rosalia conglomerate as "the breccia".

It is probable that at greater depth the fractures in the Esperanza diorite are not as open to circulation as they are near the surface. In this event the solutions would favor the more permeable Santa Rosalia conglomerate, or "breccia". Most of the ore will probably be found within the fault zone, however, since there are no known beds especially susceptible to replacement.
BIBLIOGRAPHY


PLATE 5

Figure 2

Santa Rosalia Peak. The angle from which the photograph was taken makes the hill appear deceptively low. The outcrop of the Santa Rosalia vein is dotted in ink.

Figure 3

Lowest massive limestone member of the Cretaceous sediments. Shales and thin limestone beds in foreground.
PLATE 6.

Figure 4

Crinkly limestone in creek west of Rancho Nuevo. Blocks have fallen from outcrop on bank of creek. Similar limestone appears about 12 miles north.

Figure 5

Patrick conglomerate in Driftwood Creek.
PLATE 7

Figure 6

View south from Lural limestone ridge into Driftwood Creek Valley. East Ridge at left. Ridge formed by granitic intrusive in right background.
Plate 8

Figure 7

Looking east along open cut.

Figure 8

Santa Rosalia conglomerate.
Figure 9

Fault-line scarp along Main fault. South (right) side is down-throw side.

Figure 10

Fault in East Ridge conglomerate which drops tuff (right) down against conglomerate beds.
PLATE 10

Figure 11
Esperanza diorite. Crossed nicols. x 45

Figure 12
Andesite porphyry. Ordinary light. x 45
PLATE 11

Figure 13

Esperanza dacite. Crossed nicols. x 81

Figure 14

Black basalt. Ordinary light. x 45
Plate 12

Figure 15

Lacrospherulite in Gateway rhyolite. Ordinary light. x 45.

Figure 16

Groundmass of Gateway rhyolite containing microspherulites within the rings of kaolin.
PLATE 13

Figure 17

Esperanza diorite. Ordinary light. x 45.

Figure 18

Sandstone in third member of Cretaceous section. Crossed nicols. x 26.
GEOLOGIC MAP OF ADIT LEVEL
SANTA ROSALIA MINE

EXPLANATION

Top
ANDESITE PORPHYRY

Ted
ESPERANZA DIORITE

Tsrc
SANTA ROSALIA CONGLOMERATE

Scale 1 in. = 50 ft.
Gray Is. Schistes and Nucleus interbedded shale and Is.

Gray and buff Is.

Oysters

Interbedded shales and impure buff.

Massive gray Is.

Ochitella, Kanger, Actinocyena

Shales and thin, impure Is.

Gray, massive Is.

Nonfossiliferous

Buff, impure Is. Tylastoma

Shales and interbedded Is.

Dark red, buff, gray and black shales with zones thin Is.

"Crinkly" Is.

Shale, fresh-water forms. Physa

Crinkly Is.

Dark, dark gray Is. Highly fossiliferous, mainly oysters.

Crinkly Is.

Dark red, buff, dark gray and black shales with some sandstone.

"Crinkly" Is.

Shale, fresh-water forms. Physa

Crinkly Is.