The Geology of the Blue Jay Mine Area, Helvetia, Arizona

by

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A Thesis
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the requirements for the degree of
Master of Science
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Approved: [Signature] May 27, 1937
Major Professor Date.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>iv</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Field work and Acknowledgments</td>
<td>1</td>
</tr>
<tr>
<td>Previous Investigation</td>
<td>1</td>
</tr>
<tr>
<td>Geography</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>3</td>
</tr>
<tr>
<td>Accessibility</td>
<td>3</td>
</tr>
<tr>
<td>Topography</td>
<td>4</td>
</tr>
<tr>
<td>Climate and Vegetation</td>
<td>5</td>
</tr>
<tr>
<td>History of Mining Activity in the Santa Rita and Patagonia Mountains</td>
<td>7</td>
</tr>
<tr>
<td>Sedimentary Rocks</td>
<td></td>
</tr>
<tr>
<td>General Statement</td>
<td>11</td>
</tr>
<tr>
<td>Bolsa quartzite</td>
<td>11</td>
</tr>
<tr>
<td>Cochise(?) formation</td>
<td>13</td>
</tr>
<tr>
<td>Abrigo formation</td>
<td>14</td>
</tr>
<tr>
<td>Martin(?) limestone</td>
<td>16</td>
</tr>
<tr>
<td>Escabrosa limestone</td>
<td>17</td>
</tr>
<tr>
<td>Naco limestone</td>
<td>18</td>
</tr>
<tr>
<td>Snyder Hill formation</td>
<td>18</td>
</tr>
<tr>
<td>Cretaceous(?) shales and schists</td>
<td>19</td>
</tr>
<tr>
<td>Igneous Rocks</td>
<td></td>
</tr>
<tr>
<td>Porphyritic granite</td>
<td>20</td>
</tr>
</tbody>
</table>
# Table of Contents

## Igneous Rocks (cont'd)

<table>
<thead>
<tr>
<th>Igneous Rocks</th>
<th>Page</th>
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<tbody>
<tr>
<td>Aplite</td>
<td>21</td>
</tr>
<tr>
<td>Quartz monzonite</td>
<td>22</td>
</tr>
<tr>
<td>Aplite</td>
<td>23</td>
</tr>
<tr>
<td>Rhyolite porphyry</td>
<td>24</td>
</tr>
<tr>
<td>Andesite prophyry</td>
<td>25</td>
</tr>
</tbody>
</table>

## Structure

| General geology of the Santa Rita Mountains | 27   |
| General geology of the Blue Jay area       | 27   |
| Folding and faulting                      | 28   |
| Quartz monzonite intrusion                | 29   |
| Aplite and rhyolite intrusions             | 30   |
| Lamprophyre intrusion                      | 30   |

## Metamorphism

| General Statement                  | 31   |
| Metamorphism of the Quartzites      | 31   |
| Metamorphism of the Limestones      | 32   |
| Metamorphism of the Shales          | 33   |

## Geomorphology

| General Statement                  | 34   |
| Development of Topography in the Area | 34   |
| Development of Pediments           | 35   |

## Mineral Deposits

| History of the Blue Jay Mine        | 37   |
| General Nature of Mineralization    | 38   |
| Economic Possibilities              | 39   |
Mineral Deposits (cont’d)

Aplite Hill Prospect .............................................. 41
Economic Possibilities ............................................. 42
Bibliography ............................................................ 43
The Geology of the Blue Jay Mine Area
Helvetia, Arizona

Montgomery Sherwood Dunham

Abstract

This thesis is based on field work done in the Blue Jay and adjacent areas during 1936 and 1937.

Overlying the pre-Cambrian(?) granite are Paleozoic sediments, mostly quartzite and limestones, ranging in age from Middle Cambrian to Permian. Above the Permian, in the northeastern part of the area, are Mesozoic, probably Cretaceous, shales and schists. Considerable folding and faulting occurred, probably during Laramide time. In Tertiary time an intrusion of quartz monzonite and associated minor intrusives took place. Heat and solutions from the intrusion highly metamorphosed the sediments. A well-developed, though in places alluvium-covered, pediment has been carved on the quartz monzonite intrusive.

Two mineral deposits are found in the area. The Blue Jay mine is the larger and has produced several carloads of good silver-gold ore. The ore, which is a replacement of limestone, consists of argentiferous galena in the lower levels
which has been oxidized near the surface. The main production was of cerargyrite from the oxidized zone. The Aplite Hill prospect is a quartz vein with galena and other sulphides. There has been no production from this deposit.
Field Work and Acknowledgments.

The field work upon which this thesis is based, was carried on from September, 1936, to May, 1937. The author is indebted to Drs. B. S. Butler, F. W. Galbraith, M. N. Short, and A. A. Stoyanow, of the faculty of the University of Arizona, for suggestions and assistance in field, laboratory, and office. Mr. A. B. Thomas was very helpful, and kindly permitted the reading of a private manuscript. Finally, the author wishes to thank his fellow students, Messrs. W. G. Hogue, C. D. Jeffries, W. W. Simmons, H. W. Wardwell, and especially his co-worker, Mr. L. G. Houk, for assistance in field mapping.

Previous Investigation.

Although no extensive work has been done in the Santa Rita Mountains since Dr. F. C. Schrader completed his reconnaissance survey report in 1914, information, chiefly mining reports and theses, similar to the present investigation, has been accumulating. Since the areas examined are rather widely separated, it will probably be some time before correlation is possible. The present writer had the benefit of several reports and theses, all of which may be
found in the bibliography. Besides this material, the thesis now in preparation by Mr. Herbert Alberding, on the geology of the Empire Mountains, in the vicinity of the Total Wreck mine, and the thesis by Mr. L. G. Houk on the geology of the Forbes mine, near Helvetia, will be of interest when completed.
Geography

Location

The area studied includes approximately one square mile in the northwest portion of the Santa Rita Mountains, some 26 miles southeast of Tucson, and one mile north of Helvetia. The approximate position is, Latitude 31° 52' N., Longitude 110° 47' W. With the exception of the extreme western part, the area is within the Coronado National Forest.

Accessibility

At present there are two good routes to the area. The western part is best reached as follows: U. S. Highway 89 from Tucson, south 17 miles to Sahuarita; thence east approximately one mile, across the railroad to the old Nogales road; thence south one mile to a narrow desert road; this is followed southeastward for 15 miles to a fork one mile west of Helvetia; the north fork is followed around Tip Top Mountain and east again into the area.

The Blue Jay mine is best reached by U. S. Highway 80 to Vail junction, 25 miles southeast of Tucson. From this point, a desert road leads southward to the Johnston (Stone) Ranch, and thence over a newly rebuilt road to the mine, 12 miles south of Vail. The roads, after leaving the
highway, are good, and could be put in excellent condition at slight expense.

The nearest shipping point on the railroad is Vail, on the main line of the Southern Pacific railroad.

**Topography**

In general, the area north of Helvetia is typical of the marginal foot-hills associated with mountains. The ground is uneven and hilly, but not extremely rugged. As would be expected with a maximum difference in elevation of 1,100 feet in an area of one square mile, some of the slopes are quite steep, but, with the exception of a precipitous, erosional scarp, no place in the area is very difficult to traverse. The scarp is nearly vertical to a height of about 260 feet, and is an erosional remnant of Carboniferous (probably Mississippian) limestone. The area is cut in half by this cliff, which strikes nearly north and south. West of the cliff the drainage is toward the north and northwest. On the east side the streams flow almost due north. Two rather sharp quartzite peaks are located west and northwest of the cliff. The slopes are somewhat steep and are broken by minor cliffs. East of the main cliff the limestone forms an east-west ridge with a nose making off northwest to the Blue Jay mine. A deep wash drains to the north.
One of the most interesting topographic features of the region is the development of an extensive pediment on the Tertiary quartz monzonite. The quartz monzonite has been eroded to a pediment sloping gently, and more or less uniformly, toward the Santa Cruz River, with local variations caused by small streams.

**Climate and Vegetation**

The climate is semi-arid. There are two rainy periods, one in the winter and the other in late summer. Both are of brief duration. The total rainfall averages about 15 inches, according to Forest Service records. Other weather statistics from the same source are: average maximum temperature is 108° F.; average minimum temperature is 17° F. Summer temperatures of 120° F., and above, are reached. Darkness brings suddenly decreased temperatures, at all seasons.

Field work can be carried on throughout the year, since uncomfortably low temperatures are seldom reached, even in winter, and the dry heat of summer is not oppressive.

Vegetation is of the arid type. Trees suitable for timber are absent. Only such small, bushy trees as mesquite, palo verde, greasewood, black oak, pinon pine, juniper, and desert buckthorn, are present. Cacti, catclaw, yucca, and ocatilla, are abundant. Soap weed (yucca baccata) is particularly profuse on quartzite and cherty-limestone hills.
Most of the vegetation, especially grasses, grows best on the alluvial fans, because of the greater amount of soil.
History of Mining Activity
in the Santa Rita and Patagonia Mountains\(^1\)

The Santa Rita Mountains are notable as the location of the oldest mines on the Pacific slope, north of Mexico. Here, mining was carried on by the Papago Indians before the Spanish conquest of Mexico in the sixteenth century.

The Spanish Jesuits, who explored the valley of the Santa Cruz River in 1687, were the first white men to visit the area. The first mission in Arizona was established at Guevavi, about 30 miles south of Tucson, in 1687. San Xavier del Bac and Tumacacori were built soon after. Impressed Indians, under Jesuit supervision, carried on extensive mining, as indicated by the mine workings and slag dumps still to be seen near the mission ruins.

About 1810, new discoveries were made, and, subsequently, the Spanish Government and the Jesuits vigorously pushed the conquest and settlement of the country. Missions were often destroyed by the Indians, but were re-established. Many valuable mines were worked by the Spaniards and Mexicans up to 1820.

In 1853, the Gadsden Purchase opened the region to Americans, who established mining camps as early as 1855. Several mining companies were organized and considerable work was done until the outbreak of the Civil War.

The Civil War, with the attendant withdrawal of soldiers and the activity of Apaches, put a stop to the mining industry and set back development for several years. In the early 1870's, the Indians were subjugated, and mining soon revived.

In 1879, the Southern Pacific railroad, and in 1883, the Atlantic and Pacific (now the Santa Fe) railroad, were completed. This opened the Territory to immigration and capital, resulting in increased activity in mining. Attention was then directed to copper, as well as gold and silver, mining.

In 1906, the Helvetia Copper Company operated a 150-ton copper matting furnace, and developed an important ore-body on the 800-foot level of the Isle Royal mine. Production continued from this and other mines in the district until 1908, when the industrial depression of 1907-1908 closed the mines and smelters throughout the region.

A partial revival occurred in 1909, chiefly in the Helvetia district, where development work was carried on and ore with a value of about $157,000 was shipped to the
smelter at Globe. Mining was spasmodic from 1910 until the World War, when enhanced metal prices induced much greater production. In 1916 and 1917, nearly $3,250,000² worth of ore was mined in the Santa Rita and Patagonia Mountains; the Helvetia and Patagonia districts accounting for most of it.

After the war, and until 1924, production was intermittent and generally low. However, the next six years saw increased operation, although not on a par with the war years.

Since 1930, little has been done in the region, but with the recent increase in metal prices, interest has again been revived and several mines in the Santa Rita and Patagonia districts are being examined with a view to reopening in the near future.

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## Table I

<table>
<thead>
<tr>
<th>Year</th>
<th>Helvetia Rosemont</th>
<th>Empire</th>
<th>Greater-ville</th>
<th>Harshaw</th>
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<th>Oro Blanco</th>
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<td>826,424</td>
<td>357,331</td>
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Sedimentary Rocks

General Statement

Formations present in the area include:

Cambrian: Bolsa quartzite, Cochise(?) formation, Abrigo formation;
Devonian: Martin(?) limestone;
Mississippian: Escabrosa limestone;
Pennsylvanian: Naco limestone;
Permian: Snyder Hill formation;
Cretaceous(?) schists.
The general strike is N 40° E; dip 70° E. This varies locally with the structure.

Cambrian Formations

Bolsa quartzite

The oldest sedimentary rock in the Helvetia district is the Bolsa quartzite of upper Middle Cambrian age. According to Stoyanow, the Lower Cambrian and Lower Middle Cambrian rocks were not deposited in southeastern Arizona because of a land barrier extending from Baja California to central Arizona. The Bolsa quartzite was apparently deposited on pre-Cambrian(?) granite. It is not certain that the apparent

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basement is pre-Cambrian. As will be discussed later, it is possible that a younger granite completely removed the pre-Cambrian basement, but had insufficient energy to assimilate the quartzite. In any event, the sedimentary nature is nowhere clear.

The formation, which has a thickness of about 535 feet, is composed of pinkish to very light purple, cross-bedded, vitreous quartzites with a gritty to pebbly conglomerate at the base, and a thin shaly member at the top. The quartzite members are dense and compact, and weathering produces only a rusty superficial stain. In the relatively warm and arid climate of the region, the formation is resistant and forms isolated knobs and peaks, with minor cliffs caused by sloughing along the jointing and bedding planes. The lithologic features are similar to those characteristic of the Bolsa quartzite in Bisbee and other districts in southeastern Arizona. Due to the competent nature of the rock, faulting, rather than folding, is the more common structural feature, although in places, the faulting is hidden or obscured by the tendency to slab along joints. The Tertiary(?) intrusive seems to have caused little or no metamorphism where it contacts the quartzite. This is true even to the north of the area where an extensive intrusion cuts through the entire Paleozoic section as far as the Blue Jay mine.
General Statement

Ransome\(^5\) described the Abrigo "limestone" at Bisbee as, "thin-bedded, impure, in part shaly, in arenaceous, very cherty dolomitic limestone. Carries Middle Cambrian fossils. Bed of white quartzite 8 feet at top." He gave the thickness as 770 feet. Stoyanow\(^6\), however, has more recently restricted the Abrigo formation to the Upper Cambrian, underlain by the Cochise formation (Middle Cambrian) and overlain by the Copper Queen limestone (Upper Cambrian). At Bisbee he gives the Cochise formation a thickness of 290 feet; Abrigo formation, 420 feet; Copper Queen limestone, 81 feet. The total thickness would be 791 feet.

Cochise(?) formation

Overlying the Bolsa quartzite in the western portion of the area is a rather thin-bedded, fine-grained, blue-gray limestone, 295 feet thick, containing fine, disseminated silica, and faint wavy bands of rusty chert. Although no fossils were found, the formation has been tentatively correlated with the Cochise formation of the Bisbee quadrangle. The basis for this correlation is the stratigraphic position; dissimilarity to the overlying Abrigo formation;

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\(^6\) Stoyanow, A. A., - op. cit., pp. 466-471.
and the further fact that in this area the total thickness (approximately 800 feet) of the Cambrian sediments above the Bolsa quartzite is much greater than the thickness of the Abrigo formation at Bisbee (420 feet), or in the Whetstone Mountains (430 feet).  

The lithologic character of the limestone in the Cochise (?) formation at Helvetia differs greatly from that of the Cochise formation described by Stoyanow.  The pisolithitic and oolitic textures so typical in the Whetstone Mountains, have not been observed in the area. Likewise, rather than being resistant to erosion, the bed tends to form saddles between the Bolsa quartzite and the Abrigo formation. The one point of similarity is the fact that the limestone in the area has the bluish color of the outcrops in other localities.

Abrigo formation

Resting upon the Cochise (?) formation is a series of interbedded, dolomitic limestones, rusty cherts, and hard metamorphosed shales, with a total thickness of 500 feet. Most of the individual members are one to two inches thick, but the formation contains occasional beds of limestone and

7 Stoyanow, A. A., - op. cit., p. 480.
8 Stoyanow, A. A., - op. cit., p. 480.
9 Stoyanow, A. A., - op. cit., p. 480.
metamorphosed shale one to two feet in thickness. The hard cherty and shaly bands are resistant to weathering and stand one inch or more above the weaker, dirty-gray limestone. The formation has been greatly distorted into a twisted, crumpled mass of rusty brown bands separated by gray limestone. At a distance the general color is rusty brown. Although metamorphism has altered beyond recognition any fossils originally present, the lithologic character of the formation is very similar to that of the Abrigo formation in other areas, and is believed to be sufficient evidence for correlation.

The highly metamorphosed character of the rocks in this area makes it impossible to recognize the Copper Queen limestone, if this formation is present. The white quartzite marking the top of the Abrigo formation at Bisbee, is absent.

The Abrigo formation with its distinctive lithology, makes a valuable mapping unit. The general strike is N 40° E., dip 70° E. Folding and faulting has locally changed the strike of the beds, sometimes more than 90 degrees from the general trend.
Martin(?) limestone

Above the thin-bedded Abrigo formation is a rather weak, in part arenaceous, in part argillaceous, buff-yellow, very impure, limestone. There are about 6 feet of compact green shale at the top. The thickness of the limestone is about 282 feet. This may be the Martin limestone of Upper Devonian age. However, the silicified coral reef described by Stoyanow has not been observed. Such fossils as could be found were too badly shattered for identification.

It is logical to assume the presence of Martin limestone in the area, since this formation is present in Bisbee, Tombstone, the Empire Mountains (California mine), and Rosemont, the latter only 6 miles distant. Certainly the lithologic character differs from that of the Abrigo or Carboniferous formations, so that the formation must be mapped separately. The limestone cannot be Ordovician or Silurian because the Ordovician is apparently restricted to the Clifton-Morenci district and Dos Cabezas Mountains.

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10 Stoyanow, A. A., - op. cit., p. 487.
12 Stoyanow, A. A., - oral communication.
Carboniferous Formations

General Statement

The total thickness of the Carboniferous is not known as it extends for some distance beyond the area mapped. Lack of undoubted fossil evidence prevents exact definition of the contact between the Mississippian and Pennsylvanian formations, but they have been tentatively separated on the basis of lithology.

Mississippian Formation

Escabrosa limestone

Above the parting shale members, at the top of the Devonian(?), is a massive, cliff-forming, coarsely-crystalline, marbleized, rather pure limestone. Fossils "suggesting Mississippian," according to Stoyanow, were found. The thickness of the massive bed is about 525 feet. This accords with Ransome, who described the Escabrosa limestone at Bisbee as a cliff-forming, thick-bedded, white to dark, mon-magnesian, granular limestone, made up largely

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of crinoidal material.

Pennsylvanian Formation

Naco limestone

The Naco limestone of Pennsylvanian age is much thinner-bedded than the Escabrosa limestone. Finer-grained, pinkish and dark gray, marbleized limestone beds, with a few, thin shaly members, make up the formation. No fossils sufficiently unaltered for identification were found. The total thickness is unknown.

Permian Formation

Snyder Hill formation

The Snyder Hill formation overlies the Carboniferous limestones. Permian fossils were identified by Stoyanow, and the formation was traced from the north into the Blue Jay area by F. W. Galbraith and his field geology class. The limestone is a dark blue-gray, slightly arenaceous, slightly micaceous limestone, abundantly filled with streaks of pure white limestone. These streaks vary from hairlines to 1/8-inch in width, and one to several inches in length. The top of the formation in the Blue Jay area is marked by 30 feet of brownish, somewhat muddy massive quartzite. The total thickness of the formation in the area is
390 feet. Fossils found in a Snyder Hill limestone cliff north of Johnston's (Stone's) Ranch, and identified by Stoyanow, include: *Composita mexicana* (Hall), *Squamularia cfr. guadalupensis* (Shumard), *Camarophoria deloi* (King), and *Dictyoclostus meridionalis* (McKee).

**Mesozoic(?) Formation**

**Cretaceous(?) shales and schists**

The top of the section in the area consists of Cretaceous(?) shales and schists. These are found only in the northeast corner above the quartzite at the top of the Snyder Hill formation. A considerable thickness is present, but was not determined since the formation extended far beyond the area mapped and apparently occupied the center of a syncline with a northwest-striking axis.

The formation within the area consists of grayish-white schist with pea-sized or smaller, round, green spots (epidotized), giving the beds a greenish cast, where unaltered. Much sericite is present. Weathering causes exfoliation and oxidation to a rusty-colored, friable material. Outside the area, and farther from the granitic intrusion, are found gray shales, possibly the unmetamorphosed equivalent of the schist.
Igneous Rocks.

Porphyritic granite

An extremely porphyritic, dark granite is exposed in the northwestern part of the area. The specimens collected for study were obtained from a prospect adit on Deer Hill, but identical rock extends beyond the area to the northwest. No change in character was observed, which gives the impression that the rock is part of an extensive stock or batholith. It is not certain that the granite is pre-Cambrian, since a good exposure of the granite-Bolsa quartzite contact could not be found. As the rock is very similar to probable pre-Cambrian granite near Tombstone, and as it appears to underlie the Cambrian sediments, it has been tentatively assigned to the pre-Cambrian.

The hand specimen is very porphyritic. Phenocrysts of feldspar varying from 1 to 5 centimeters in maximum length, with an average length of 2 centimeters, are scattered throughout the rock. An abundance of mafic minerals, mainly biotite, gives the rock a dark appearance. Under the microscope, the rock is found to consist of 20 percent orthoclase in grains averaging 5 millimeters; 25 percent of slightly kaolinized and considerably sericitized microcline in subhedral grains averaging 1 centimeter in length; 25 percent anhedral quartz grains averaging 3 millimeters in
diameter; and 15 percent biotite occurring in interlocking segregations and as single grains widely disseminated between the phenocrysts. Accessory minerals are magnetite, muscovite, and hornblende, each constituting less than 5 percent, and occurring in grains 1 to 3 millimeters in diameter.

Some of the quartz forms a mosaic pattern which indicates either that the quartz is a recrystallization of once homogeneous grains, or has been introduced after final solidification.

Aplit

An aplite dike about 50 feet thick is exposed in the adit on Deer Hill. The same dike is exposed in the main wash draining the canyon between Deer Hill and Round Top. The thickness was obtained at the latter point.

In hand specimen, the aplite is essentially equi-granular, with a fine sugary texture. The color is nearly white, with a pinkish cast. Magnetite, the only dark mineral, constitutes less than 1 percent of the rock. The mineral grains are too small to identify macroscopically.

Thin sections show the rock to consist of nearly 50 percent quartz, 20 percent microcline, 15 percent albite, 10
percent orthoclase, and 5 percent muscovite. All the mineral grains average 0.5 millimeter in diameter. Kaolin, the only alteration mineral present, is incipiently associated with the orthoclase.

With only two exposures, it is difficult to determine the age of the dike. Both exposures of the dike are associated with the pre-Cambrian granite. Since, in the Blue Jay area, the Tertiary intrusions appear to have followed the faulting, and the aplite dike shows considerable displacement, it seems probable that the dike is pre-fault, and hence, pre-Tertiary. As there are no indications of intrusive activity between Cambrian and Permian time, it would appear to be safe to assume that the dark granite and the associated aplite dike are both pre-Cambrian, the aplite being considered a late differentiation product of the dark granite.

Quartz monzonite

Intruding the entire Paleozoic section, and also what are believed to be Cretaceous schists and shales, is a light-colored, coarse-grained, quartz monzonite which is believed to be of Tertiary age. The type specimen was collected on Aplite Hill, in the southwestern corner of the area, but similar rock crops out here and there over a wide area, indicating that the intrusion was extensive. Probably it is a facies of the intrusion which forms a considerable
part of the Santa Rita Mountains.

The rock is nearly white, has a coarse-grained, granitic texture, and is composed of quartz and feldspar with a very small amount of mafic minerals. Some facies of the rock are porphyritic with phenocrysts of feldspar measuring 2 centimeters in length.

In thin section, microperthite, in grains averaging 4 millimeters in length, makes up about 40 percent of the rock. Oligoclase, incipiently sericitized and extensively kaolinized, occurs in subhedral fragments up to 5 millimeters in length, and constitutes 25 percent of the rock. Rounded quartz grains averaging 4 millimeters in diameter make up another 25 percent.

Accessory minerals are, magnetite, apatite, and hornblende, all about 1 millimeter or less in maximum length. Together they form not more than 4 percent of the whole.

Alteration minerals are kaolin, extensively associated with the oligoclase, sericite subordinately associated with the same mineral, and muscovite in grains up to 0.2 millimeter in diameter, also altered from oligoclase. The hornblende has almost completely altered to chlorite, which occurs in grains up to 0.8 millimeter long.

Aplite

An aplite dike, about 75 feet thick, on Aplite Hill,
is the largest intrusion of an aplitic nature in the area. The dike is resistant to weathering, and, hence, well exposed. Smaller tongues of similar aplite intrude the quartz monzonite throughout the area. None are more than 10 feet thick. All have the same sugary texture and pinkish color.

Microscopic examination shows the rock to be rather equigranular with a few scattered subhedral crystals of orthoclase measuring 1 millimeter long, and rounded quartz grains 1 millimeter in diameter.

The average grain size is 0.3 to 0.4 millimeter. The essential minerals are quartz, 30 percent; orthoclase, 35 percent; microcline 20 percent; and albite, 10 percent. Biotite, muscovite, and magnetite, are the accessory minerals, and together constitute less than 5 percent. Secondary muscovite has developed to some extent. The albite shows incipient sericitization. Microcline is slightly kaolinized. The sequence of crystallization is: albite, microcline, orthoclase, muscovite, and quartz.

Rhyolite porphyry

In the canyon between Deer Hill and Round Top in the northwestern part of the area, a rhyolite porphyry dike about 20 feet thick is exposed. Several smaller tongues of the same rock intrude the quartz monzonite in the vicinity. The rock is light gray with an aphanitic groundmass and
phenocrysts of pink feldspar and rounded quartz. Small grains of magnetite are scattered sparsely throughout.

The thin section shows the rock to consist of phenocrysts in a groundmass of micrographic intergrowth and devitrified glass. Orthoclase in subhedral phenocrysts, averaging 5 millimeters in length, makes up about 25 percent of the rock. Another 25 percent of orthoclase occurs with quartz in micrographic intergrowth. Well-rounded quartz grains from 1 to 2 millimeters in diameter are scattered sparsely throughout the rock. Together with that in the intergrowth, the quartz content is about 25 percent. Devitrified glass, showing spherulitic texture, makes up the remaining 25 percent. Magnetite is widely disseminated in grains up to 0.5 millimeter. Chlorite and secondary muscovite are present in grains averaging 0.5 millimeter in length. The orthoclase displays incipient sericitization.

Andesite porphyry

Near the Blue Jay mine in the northeast corner of the area is a dark green dike of andesite porphyry about 30 feet thick. Macroscopically, the rock is dull and appears altered. Light colored phenocrysts of feldspar up to 3 millimeters in greatest dimension, and dark green blebs of some mafic mineral about 2 millimeters in diameter, are sparsely disseminated.
The thin section shows phenocrysts, up to 3 millimeters in length, with the outline of plagioclase feldspar, but extensive sericitization prevents definite determination. The texture is andesitic, but borders on the basaltic. Besides sericite, other alteration minerals are chlorite and magnetite. Calcite has been introduced after solidification.
Structure

General geology of the Santa Rita Mountains

"The range consists of a granitic axis of probable pre-Cambrian age, flanked by overlapping and locally highly tilted Cambrian(?) to Cretaceous sedimentaries, which, except the Cretaceous, have been invaded by Mesozoic intrusives and all covered by Tertiary volcanics. The structure in general is monoclinal with the dip gently to the east and the trend northwesterly. Areaally, the igneous rocks are dominant."

The area studied by the writer is too small to permit much discussion of the structure of the Santa Rita Mountains. In the Blue Jay area, the intrusion was probably of Tertiary age.

General features of the Blue Jay area.

The structure of the Blue Jay area is rather complex. Faulting is very common. In the more thin-bedded and shaly formations, especially the Abrigo formation, drag folding is associated with the faulting. In the more massive Escabrosa limestone there is some gentle folding. The sedimentary rocks of the area may be on the steeply-dipping east limb of an anticline with a north-south strike. Many of the fault zones are intruded by lamprophyre dikes two to ten feet thick. One extensive fault, cutting through the Blue

Jay mine, is masked in its westward extension by an invasion of quartz monzonite. Folding, but no faulting, was observed in the Cretaceous (?) schists; in places these were also invaded by tongues of the intrusive. The structural disturbance is believed to be mainly pre-intrusion. The intrusion is believed to be Tertiary, as Cretaceous (?) formations were invaded.

The probable sequence of structures is:

1. Strong anticlinal folding with the strike north-south.
2. Folding and faulting of the steeply dipping beds.
3. Intrusion of quartz monzonite.
4. Intrusion of aplite and rhyolite porphyry dikes in the quartz monzonite stock.
5. Intrusion of lamprophyre dikes along some of the fault zones.

Folding and faulting

As already suggested, the area may be on the east limb of a north-south anticline. If so, the west limb is represented by a westerly dipping limestone, half a mile northwest of the Forbes mine, and about one mile west of the area. This anticline, if it existed, was asymmetrical with the steeper dip to the east. Within the Blue Jay area, there are no indications of extensive faulting at the time the anticline was formed.
Later, there was a series of roughly parallel, high-angle faults with a considerable horizontal element of movement. The strike is generally west-northwest. From south to north the fault blocks are in a step pattern with the north blocks pushed progressively farther east. Opposite Escabrosa Cliff, conditions are reversed, and from south to north, each block is pushed farther west. To the eastward the fault movement was absorbed by gentle folding and subordinate faulting of the massive Escabrosa limestone. The fold pitches very steeply to the east.

The total displacement of beds by faulting is about 1,900 feet, as determined by the positions of blocks of Bolsa quartzite. The major structures have been assigned to the Laramide period, but without definite evidence for close dating.

Quartz monzonite intrusion

Subsequent to most of the faulting and folding, there was an extensive intrusion of the area, probably in Tertiary time. Because of the widespread similarity of the igneous rock, it is believed that the quartz monzonite is a facies of the intrusive which makes up a considerable part of the Santa Rita Mountains. Although no folding or faulting was observed to be definitely associated with the intrusion, it is difficult to believe that such an extensive intrusion could have occurred without some structural disturbance.
The quartz monzonite is exposed along the entire western boundary and northeastern portion of the area. It was the source of the heat and solutions which metamorphosed the Paleozoic limestones and Cretaceous (?) shales.

Aplite and rhyolite intrusions

Very late in the igneous cycle, a number of dikes of aplite and rhyolite porphyry were intruded into the quartz monzonite stock. The dikes vary from one inch to 75 feet in thickness. Little structural disturbance resulted from these minor intrusives.

Lamprophyre intrusions

Many of the fault zones contain dark green lamprophyre dikes, usually not over ten feet thick and averaging about three feet. Like the aplite dikes, these intrusions caused little or no disturbance. In the Blue Jay mine and the adjacent wash, occurs a dark green sill of lamprophyric nature, apparently (as described under Igneous Rocks) of andesitic, bordering on basaltic, composition.
Metamorphism

General Statement

Metamorphism in the area has been extensive. In the main it has consisted of cementation and recrystallization of sedimentary rocks, although in places some material has been added by the intrusive. The recrystallization is best represented by the extensive marbleization of the limestones, with lesser induration of the shales. The metamorphism of the quartzites consisted of cementation. Material added to, or recrystallized in, the limestones, has formed wollastonite and silica. In the shales and schists are found epidote and sericite.

Metamorphism of the Quartzites

It is uncertain when the sandstone was metamorphosed into Bolsa quartzite. It would appear from the presence of conglomeratic and arkosic material and beds of relatively coarse sand, that the formation was originally permeable, so that cementation was accomplished by circulating solutions, thermal or otherwise. The presence of a shaly member at the top of the formation would indicate that the solutions were probably not meteoric, although such solutions might have circulated downward along the dip after a certain amount of tilting. It is possible that the so-called pre-Cambrian
granite was later than the Bolsa quartzite so that solutions from the granite effected the cementation. Another possibility is that connate water may have been heated later, causing rearrangement of the silica and cementation. Since the formation appears to have been very competent at the time of greatest deformation (probably Laramide), it is very questionable if deformation was the cause of metamorphism. One must conclude then, that the most plausible origin is that of silica-rich waters circulating through the original sandstone and causing cementation of the grains.

The quartzite present in the Snyder Hill formation probably had an origin similar to the Bolsa quartzite. In this case, however, the circulating solutions could very well have come from the Tertiary intrusion.

Metamorphism of the Limestones

The purest limestones, such as the Carboniferous and parts of the Devonian(?), have formed the purest marbles with the largest calcite crystals. In the Escabrosa limestone, calcite crystals one inch and more in length are found. The argillaceous and arenaceous limestones such as the Cochise(?), Abrigo, some beds of the Martin(?), and the Snyder Hill formations, are not so completely recrystallized and do not exhibit calcite crystals longer than one millimeter. Just how much of the fine silica present in the
marbles was introduced, and how much was original, is not known. Some wollastonite is associated with the Carboniferous limestones. Silification and minor epidotization occurs in a few places in the Escabrosa, Naco, and Snyder Hill formations. The silification is not nearly as extensive as it is farther to the southwest, near the Forbes (Tip Top) mine. Epidotization is restricted to the more impure members of the formations. No garnet zones were observed.

Metamorphism of the Shales

In the Abrigo formation the thin shale members have been indurated by silification to resistant layers standing one inch and more above the limestone.

The Cretaceous(?) shales have been metamorphosed to schists for several hundred feet from the late intrusive contact. Schistosity, epidotization, and much sericitization are the result. Probable causes of the metamorphism are heat, pressure, and introduction of thermal solutions. In thin section, the rock is composed almost entirely of scattered epidote spots, surrounded by sericite. The unmetamorphosed shales farther to the north, away from the intrusive contact are darker in color and rather massive, with little or no sericite or epidote.
Geomorphology

General Statement

The area lies within the Basin and Range Province, on the boundary between the Sonoran desert and Mexican highland section. The physiographic development has been controlled by climate, lithology, and structure. The maximum relief is about 1,100 feet. Escabrosa Cliff is the highest point, with an elevation of 4,994 feet.

Development of Topography in the Area

The area is semi-arid, with no perennial streams, although two or three small springs issue from the limestone to the south, flow a few feet, and sink into the gravel. Erosion during the dry season is slight. However, some of the summer rains are torrential and the surface is eroded rapidly for a short period. Many of the washes are deeply and steeply cut. The lack of water during most of the year prevents the growth of any but desert vegetation. In turn, the small amount of vegetation offers little protection from the torrential rains of summer.

Like any arid region of middle to upper altitude, the disappearance of the sun brings a very sudden drop in temperature. Although this change has little effect upon the relatively dense, homogeneous rocks such as Bolsa quartzite and Escabrosa limestone, the effect upon the coarsely crystalline, porphyritic intrusive rocks is marked, and both the granite and the quartz monzonite are rapidly broken down to fine gravel. In general, the topographic lows are a reflection of granite weathering and erosion; whereas the Bolsa quartzite and Escabrosa limestone stand up well under the climatic conditions.

Faulting has played an important part in the development of the area, particularly with respect to drainage. Many of the streams in the more rugged part of the area flow, for some distance, along fault zones, most of which, however, are too minor to show on a map of the scale used. Minor cliffs of the resistant Escabrosa limestone and Bolsa quartzite occur where the blocks have been pushed or thrown out of the original position. Cliffs of major proportions, such as Escabrosa Cliff with a nearly vertical face over 250 feet high, have been formed as erosional remnants of steeply dipping (70°) beds.

**Development of Pediments**

Pediments are well developed in the region. The Tertiary
quartz monzonite has been weathered and eroded, in and around the area, to a pediment which slopes gently and uniformly toward the northwest and the Santa Cruz River. In most places, a thin covering of alluvium obscures the rock surface, but in the deeper washes the exposures can be seen. This gravel veneer is due, apparently, to lessened erosion in the present subcycle. In the area mapped, the slope of the pediment is locally changed by stream erosion, as would be expected. Nowhere in the area can the thickness of alluvium be over 20 feet.
History of the Blue Jay mine

The Blue Jay mine, about two miles south of the Johnston (Stone) Ranch, was discovered in 1881. In 1882 it was sold to the Iowa Mining and Development Company of Cedar Rapids, Iowa, which company retained possession until 1920, when it was sold to Harold Wealton. In 1922, Eleanor T. Randolph bought the property and owned it until 1936, when she sold it to A. B. Thomas.

The property consists of seven unpatented claims, Good Friday, Good Friday No. 2, St. Louis, Cedar Rapids, Blue Eagle, Blue Flag, and Blue Jay.

In 1884 a mill was built, but proved unsuccessful, and the company began shipping their ore. Three carloads of ore netting $60 per car were shipped, and 250 tons of "good second-grade ore" were sold to the Tucson Sampling Works. Later, ore was shipped to El Paso. Although a steady producer from the time of discovery until 1902, the mine was not profitable. In 1902, lessees produced four carloads of ore that averaged 140 ounces of silver and $8. (at $20.67 per ounce) in gold per ton. In 1907, five

carloads of ore, containing 300 ounces of silver and $8. in gold per ton, were mined and shipped.

In 1914, there was an aggregate of 3,000 feet of workings. This included four tunnels, several shafts, drifts, crosscuts, stopes, and winzes. The lowest tunnel opens in the Snyder Hill formation on the northeast side of Blue Jay Hill and trends S 54° W. It crosscuts the formation and ends in the quartz monzonite, about three-quarters of the way through the hill and 25 feet beyond the main ore shoot. The other three tunnels open on the northwest slope and trend southeastward.

**General nature of mineralization**

The deposit seems to be restricted to the Snyder Hill formation, which strikes northwest and dips steeply to the northeast. In the stopes cut from the main tunnel, the mineralized zone averages about 10 feet in width. In the wash to the northwest, the Snyder Hill limestone, immediately under the quartzite of the same formation, is sprinkled with specks of galena. A selected sample, assayed by J. L. Draeger, showed 5 ounces of silver per ton.

No extension of the ore into the quartz monzonite is
indicated as Schrader points out. In general the deposit seems to be of the limestone replacement type. No copper minerals were found. Schrader reported the presence of argentite, galena, pyrite, and a little copper stain. The surface ore contained considerable cerargyrite.

Specimens of black-coated limestone, reported to contain molybdenite, gave no trace of molybdenum when tested by the writer. The black-coating proved to be carbon.

There is no indication of more than one period of mineralization.

Economic possibilities

Mr. Thomas reported to the author that assays of unbroken rock in the mine ran as high as $12. in gold and silver per ton, with small amounts of molybdenum and no copper. He further stated that samples from the dump averaged $9.71 in gold and silver. Schrader reported high grade shipping ore. All work done in the mine in the past has been by hand methods, and the ore was carried by wagon to the railroad. No concentrating was done. The writer

17 Schrader, F. C., - op.cit., p. 133
18 Schrader, F. C., - op. cit., p. 133
19 Schrader, F. C., - op. cit., p. 133.
has not sampled the mine or dumps, and has not estimated the amount of ore developed. Very careful sampling is necessary, especially of the dumps, before any work should be considered. The mine has yielded some rich ore and it is possible that additional bodies of ore may remain to be found.
Aplite Hill prospect

The Aplite Hill prospect, owned by Lito Charles, consists of a conspicuous and regular vein about four feet thick, striking N 80° E with little deviation and dipping 80° to the south. The vein is composed principally of white, coarsely crystalline quartz, with a rusty stain on the surface and along the fracture lines. Associated with the quartz are small amounts of chalcopyrite, covellite, galena, and pyrite. In a prospect pit, on the west slope of Aplite Hill, a half-inch seam of specular hematite is exposed. The quartz vein cuts the quartz monzonite and extends into the Abrigo formation as it is followed eastward a few hundred feet off the area.

Development includes a drift about 40 feet long, and several pits and trenches. No extensive work has been done. According to Mr. Charles, the vein in the face of the tunnel carried "a little silver, and a dollar or two in gold."

The mineralization observed in the vein consists of well crystallized white quartz with galena and subordinate chalcopyrite filling the interstices between the crystals of quartz.

Charles, Lito, - oral communication.
Economic Possibilities

The economic possibilities of this prospect seem slight. It does not carry sufficient metal to be profitable near the surface, and supergene enrichment of silver is problematical.
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