NEVADA BUREAU OF MINES

Vernon E. Scheid, Director

BULLETIN 56

GEOLOGY OF THE CANDELARIA MINING DISTRICT, MINERAL COUNTY, NEVADA

By

BEN M. PAGE

UNIVERSITY OF NEVADA

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FOREWORD

Nevada Bureau of Mines Bulletin 56, "Geology of the Candelaria Mining District, Mineral County, Nevada," by Ben M. Page, is based on field studies made by the Stanford Geological Survey, Geology Department, Stanford University, during three field seasons—1939, 1948, and 1949. Dr. Page, who is Professor of Geology at Stanford University, revisited the district in 1952 and 1953, in order to check and revise the maps and to bring the statistics and other data up to date, preparatory to writing this report.

Since its discovery in 1863, the Candelaria district has produced an estimated $15 to $20 million. Most of this came from silver ores, but some gold, lead, zinc, and antimony was produced. Today, Candelaria is a ghost town, with only a few buildings standing as evidence of its past importance. Its interesting early day mining activity is recalled by well-preserved examples of careful stone work and fine, hand-polished wood work, done by Chinese laborers. This stone work still may be seen in the lower levels of the Mt. Diablo Mine. After the period of its boom, in the latter part of the last century, desultory mining was practiced in Candelaria for many years; however, during the past decade there have been steady, but limited, mining operations.

Although an excellent study of the regional geology of the country surrounding Candelaria, entitled "Geology of the Mina Quadrangle, Nevada," was published in 1954 by Ferguson, Muller, and Cathcart; the present report is the first important study of the mining district since "The Candelaria Silver District, Nevada" was published in 1922 by Knopf. Professor Page's report is a very timely contribution to our knowledge of the mineral deposits of Candelaria. His detailed mapping of the district and the regional geological studies of Ferguson and others provide valuable new information for the exploration of ore deposits at Candelaria.

The Nevada Bureau of Mines is grateful to Professor Page for the opportunity to publish his report and to make it available to the mineral industry.

VERNON E. SCHEID, *Director*
Nevada Bureau of Mines.

November 1958.
Mackay School of Mines,
University of Nevada.

GEOLOGY OF THE CANDELARIA MINING DISTRICT, MINERAL COUNTY, NEVADA

By Ben M. Page

ABSTRACT

The Candelaria district of western Nevada produced an estimated $15,000,000 to $20,000,000, principally from oxidized silver ore mined in the 1870's and 1880's. Activity during the past 50 years has been limited for the most part. There are possibilities, not yet thoroughly tested, for the mining of sulfide ore and recovery of small to moderate amounts of silver, gold, lead, zinc, and antimony.

The oldest rocks of the district are chert and dolomite of the Palmetto formation (Ordovician). These are overlain unconformably by a thin grit bed, the Diablo formation (Permian). The next sedimentary rock, the lower beds of which contain most of the mineral deposits, is shale of the Candelaria formation (Lower Triassic). A serpentine mass and a variety of dikes cut the sedimentary beds.

Two major pre-Tertiary orogenies are clearly indicated. The earlier of the two was post-Ordovician and pre-Middle Permian in age; it produced tightly compressed folds and numerous fractures in the Palmetto formation prior to the deposition of the Diablo formation. The second major orogeny was Jurassic (?) in age; it affected the Diablo and Candelaria formations, which are steeply inclined and are displaced by faults.

Mineralization ensued after most of the Jurassic (?) folding and faulting was completed, but it was probably related to the later stages of the orogeny. The fractured rocks were hydrothermally altered to dolomite and other products. Then faulting recurred, forming fissures which became veins through the action of mineralizing solutions. These solutions deposited quartz, additional dolomite, pyrite, arsenopyrite, sphalerite, galena, and jamesonite. The last two contain silver, and some silver may occur in the other minerals as well.

After the formation of the ore deposits, and after an interval of erosion, Tertiary volcanic outbursts blanketed the area with at least 2,000 feet of pyroclastic rocks and lava. Dacitic and rhyolitic rocks predominate, but two or three basalt flows are interbedded with these.

Gentle folding and extensive normal faulting affected all pre-Quaternary rocks, together with the mineral-bearing veins. After an interlude of erosion, thin flows of basalt spread over much of the area, probably in the Pleistocene. Block faulting of "Basin and Range" type displaced the Quaternary basalt flows, further dislocated the ore deposits, and may have continued into the Recent epoch. The two principal faults participating in this movement trend east-northeast to east, and are old faults which were revived in the Quaternary period.

INTRODUCTION

GEOGRAPHY

This report deals with the Candelaria mining district[1], western Nevada. The area described is mainly within Mineral County, where the mines are situated, but it extends slightly into Esmeralda County. The locality is 17 miles straight line distance south of Mina, and 47 miles west of Tonopah (fig. 1). It is shown in

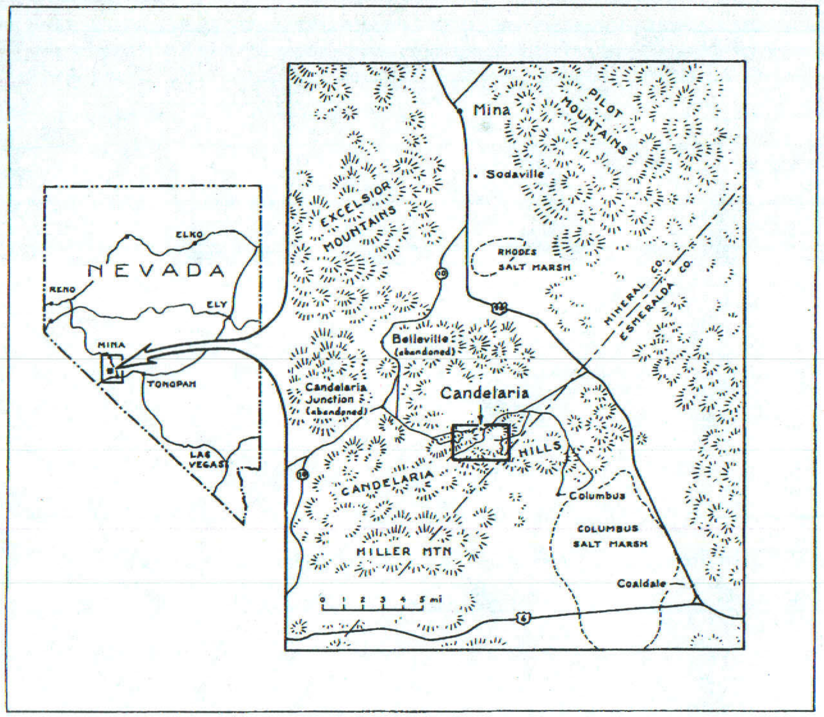

FIGURE 1. Index map showing location of the Candelaria mining district, Nevada

the southeast quarter of the Hawthorne 1-degree quadrangle of the U. S. Geological Survey.

The ghost town of Candelaria, near the principal mines, is the chief landmark. It may be reached from U. S. Highway 95 by a 7-mile dirt road which leaves the highway between Coaldale

[1]Originally included in the Columbus mining district. The name "Columbus" appears in many claim notices and old records.

Junction and Mina. The Nevada and California Railroad, which appears on many maps as a means of access to Candelaria, no longer exists. The pipe line and reservoir shown on pre-World War II maps likewise no longer exist. The nearest water supply is at Columbus, 5 miles away, and the nearest source of supplies is at Mina. At times Candelaria has not a single inhabitant.

The ruins of Candelaria (figs. 2 and 3) are situated on a small, sloping alluvial plain at the foot of the Candelaria Hills. This range of hills trends generally east-west, and is ill-defined and sprawling except west of the townsite, where a single narrow horst forms a straight-sided block. Hillsides are steep and bare, the bedrock being widely exposed, but summit areas are locally broad and gentle in slope.

The terrain of the district is 5,500 to 6,700 feet above sea level, and is arid sagebrush country. Temperatures are high in summer but frequently below freezing in winter.

HISTORY OF MINING

An excellent summary of the early history of mining in the Candelaria district is given by Knopf (1922, p. 3–5)[2], as follows:

"The silver veins in the Candelaria Mountains were discovered by a company of Spaniards in 1863, and a mining district was organized in the same year. The veins themselves crop out in a particularly barren and inhospitable part of Nevada, and the town that grew up, called Columbus, was situated where water was obtainable, 5 miles southeast of the principal mines, on the western edge of a great alkali flat, the Columbus salt marsh. In 1867 the town had 200 inhabitants, many of whom were doubtless dependent on the salt industry, for in those days the metallurgic plants of Nevada consumed a large quantity of salt; but the work that had been done to prove the silver veins of the district was small. Ross Browne, writing at that time, says that crushings of small lots of ore yielded from $50 to $200 a ton, 'a good result considering the quantity of ore of this class that can easily be obtained; so that the prospect is not unfavorable.' The remoteness of the district, the complex metallurgic treatment required by the ores, and the fact that the veins were held in numerous small holdings all combined to retard the growth of the new camp. Not until the middle of the seventies did the district come into its own, but then, owing to the successful development of the Northern

[2]Knopf acknowledges the following principal sources of information: Biennial reports of the State Mineralogist of Nevada for 1870–1880; and Annual Reports of the Director of the Mint upon the production of precious metals in the United States, for 1880–1884. Knopf's specific references have been inserted parenthetically in the passages included here, and the cited articles are listed at the end of this report along with those that were consulted by the present writer.

Belle mine, it became the most productive silver camp in Esmeralda County and one of the foremost in Nevada.

"Two 20-stamp mills, erected 8 miles west of the mines at Belleville, where water is available, were put in operation, one in 1873 and a second in 1876. Roasting furnaces were also installed, for the ore was refractory and required preparatory roasting. In April 1875, the Northern Belle began paying monthly dividends, and for a period of ten years it produced annually a million dollars in bullion.

"The success of the Northern Belle mine led inevitably to the growth of a town near the mine, the present Candelaria, which was started in 1876. Prosperity was everywhere apparent at this time. The town grew large enough to support a newspaper, and on June 5, 1880, the Candelaria True Fissure appeared for the first time. In naming his paper thus the editor was regarded as having made a peculiarly happy stroke. The name was intended to convey the thought that the Northern Belle and the other mines of Candelaria were on a true fissure vein, 'which was the hope of every camp in Nevada which aspired to rival the Comstock lode.' (Drury, in Davis, 1913, p. 484).

"A water system was completed in 1882, which brings water from the White Mountains through a pipe line 27 miles long. . . . In March of the same year the Carson & Colorado Railroad, a narrow-gage line projected in 1880, reached Candelaria by a branch from the main line near Belleville and gave the camp much needed transportation facilities, connecting it with the transcontinental line of the Central Pacific by way of Mound House, near Reno. In later years, after the discovery of Tonopah in 1900, the narrow-gage line was taken over by the Southern Pacific system, changed to a broad-gage line as far as Mina, 25 miles from Candelaria, and renamed the Nevada & California Railroad.

"Litigation broke out in 1883. The Holmes Mining Co., whose property adjoined that of the Northern Belle Co., sued that company for trespass and asked for $1,500,000 damages in compensation for ore taken from its ground. The jury gave their verdict in favor of the Holmes Co. and awarded it $360,000 damages. Thereupon the Northern Belle Mining Co. ceased operations and wound up its affairs. The mine at Candelaria and the reduction mills at Belleville were sold by the United States marshal on March 20, 1884, and were purchased by the Holmes Mining Co. The Northern Belle, after having yielded $10,000,000 in bullion and $2,122,500 in dividends, thus went out of existence. The Holmes and the Northern Belle were consolidated as one mine, which has since the consolidation been known as the Argentum."

Strictly speaking, the Northern Belle mine did not go out of existence; it is still known by that name. However, the Northern Belle Mining Co. was superseded by the Argentum Mining Co., an organization which has continued to the present.

"About this time the Mount Diablo mine became a heavy producer, and in 1883 it began paying its first dividends. The richness

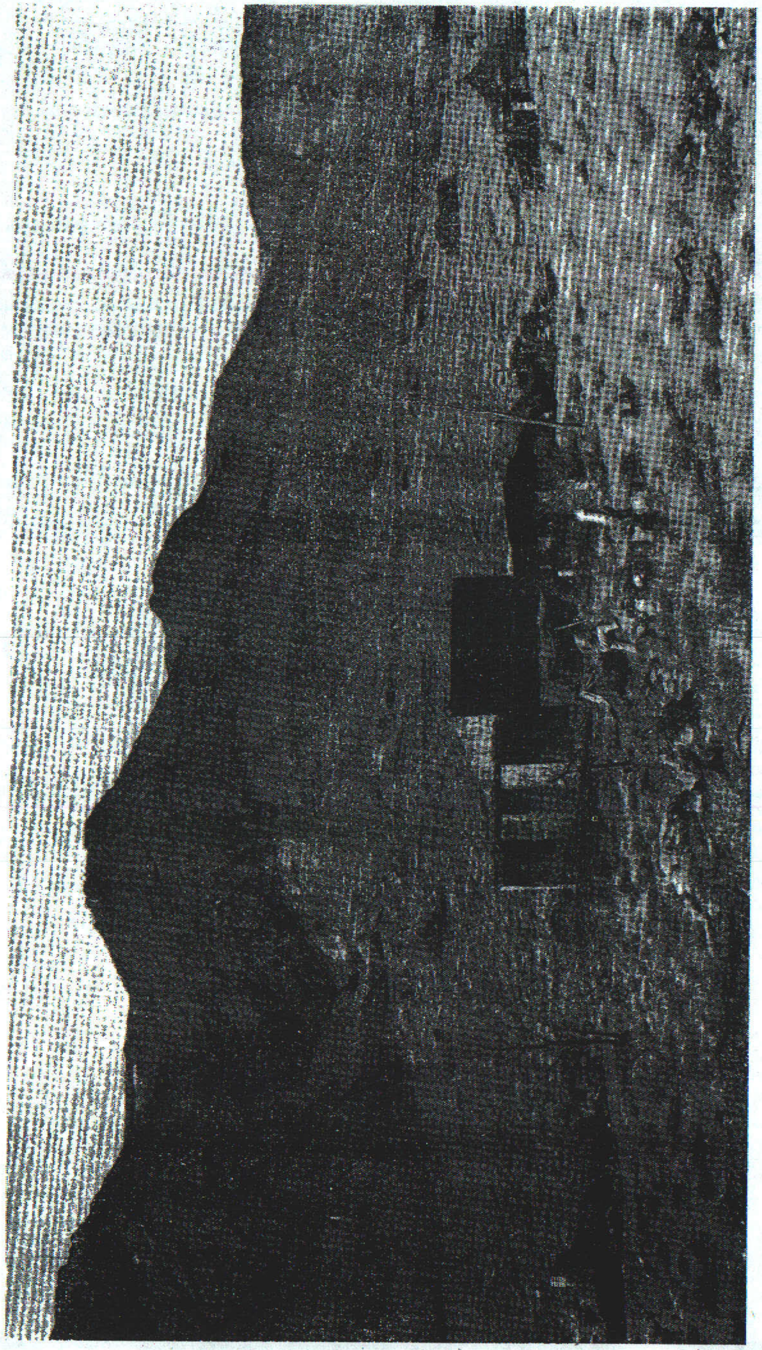

FIGURE 2. Ruins of Candelaria, 1948. Candelaria Mountain in background. Trace of Candelaria fault is visible at juncture between bedrock and talus slope at foot of mountain. Dumps at left belong to the Holmes and Northern Belle mines of the Argentum Mining Co.

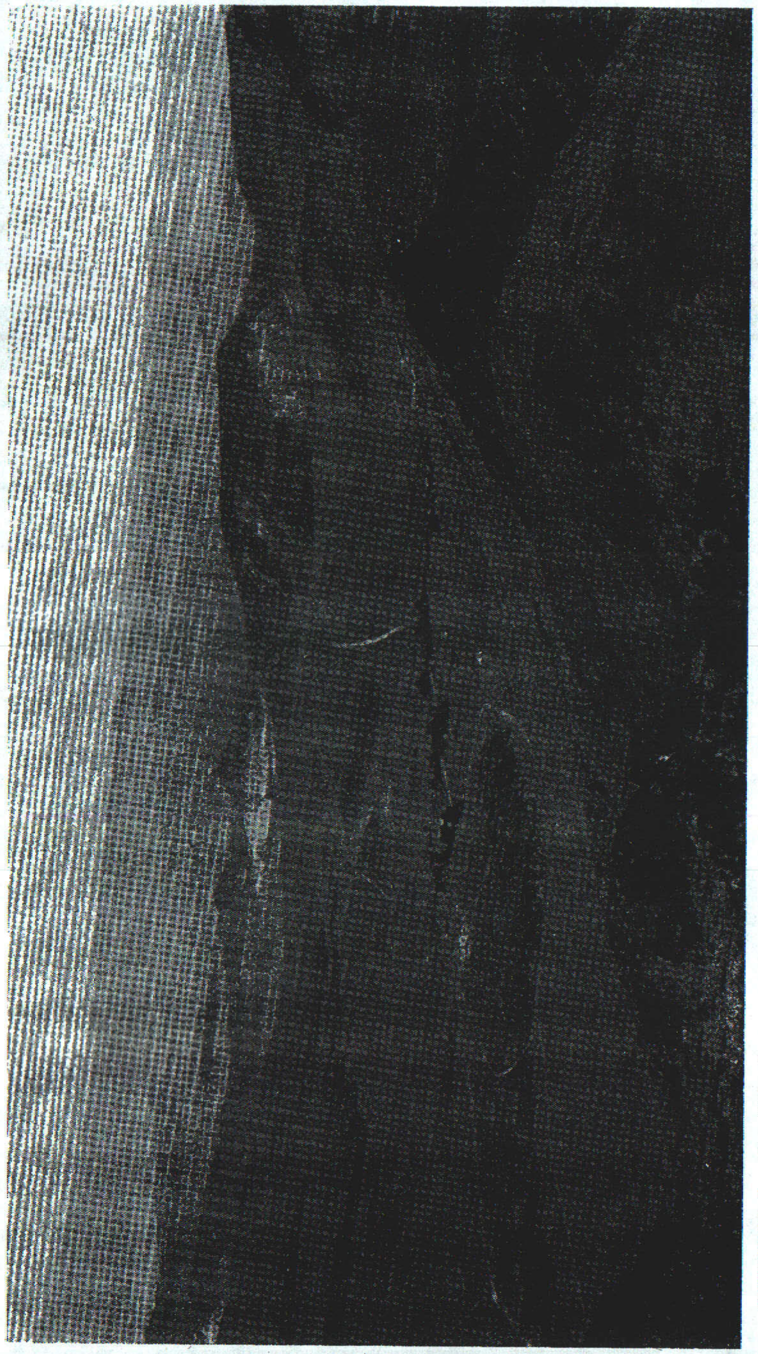

FIGURE 3. Candelaria, as seen from Candelaria Mountain, 1939. Quaternary basalt forms a sloping surface at left which passes beneath the town and reappears at high elevation at far right center, the basalt having been offset by the Candelaria fault.

of the ores then available is perhaps shown most impressively by the fact that the total cost per ton of ore treated in 1883, including charges for mining, milling, transportation, overhead, taxes, and other expenses, was $44; nevertheless, the mine was able to pay dividends. The ore milled in 1883 yielded $56 a ton in bullion; as mined it must have carried at least $65, or roughly 60 ounces of silver to the ton. In the Callison stope there was a body of ore from 100 to 140 feet long; it was worked for 110 feet on the dip, and in the widest place it contained 12 feet of $200 ore." (Rept. of Director of the Mint for 1883, p. 510–511).

The Potosi[3] mine also was active during the hey-day of the Northern Belle and the Mount Diablo (the veins were well known as far back as 1868), but this mine was overshadowed by the other two.

The height of the prosperity lasted from 1875 to 1886 or slightly beyond. By the 1880's and 1890's, Candelaria had several score buildings (figs. 4 and 5). The district declined rapidly after 1891. From that year until 1914 few data were published, and the occasional production figures are all less than $30,000 for a year's output of ore. During this epoch, the literature refers to a few of the smaller mines; for example, the Georgine, mentioned in 1905 and 1906; the Potosi, 1907 and 1909; and the Swastika or Bi-metallic, 1911 to 1914, inclusive[4]. Most of the smaller mines had been opened in the 1870's and 1880's, but received comparatively little publicity.

The re-treatment of mill tailings at Columbus resulted in a small recovery in 1913, and cyanidization of tailings at Belleville yielded substantial recovery of silver, gold, copper, and lead, 1915–1918.

A brief revival of mining at Candelaria began in 1918, when the Candelaria Mines Co. was formed. This company leased the Northern Belle (or Argentum), Mount Diablo, and Lucky Hill mines from the Argentum Mining Co. After extensive sampling and the first detailed geological work in the district (by J. A. Burgess), the company in 1920 began intensive development of the Lucky Hill mine. This mine had been opened during the 1870's or 1880's, and had produced during that period and at intervals thereafter. The Candelaria Mines Co. completed a 150-ton mill at Candelaria in 1922, and operated it and the Lucky Hill mine during the following year. According to H. G. Ferguson (personal communication, 1955), much of the production consisted of old fill recovered from stopes. The project soon ended and the mines reverted to the Argentum Mining Co.

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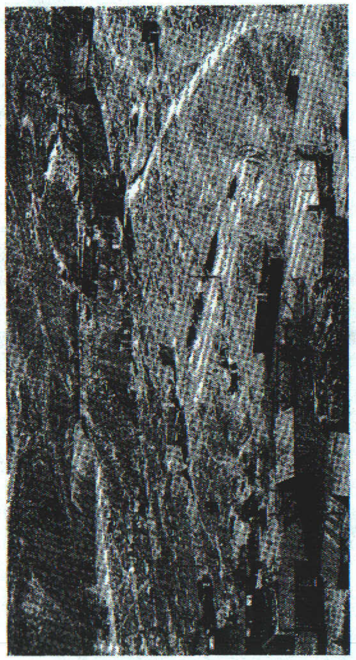
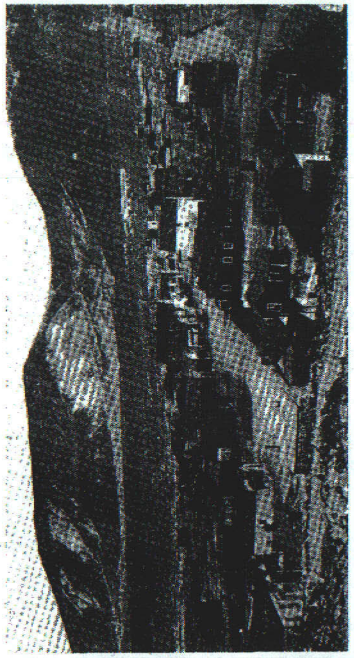
[3]Also known as Mt. Potosi and New Potosi.

[4]Various authors, "Mineral Resources of the United States": U. S. Geo-





FIGURES 4, 5. Candelaria, probably in the 1890's (Courtesy Mr. M. C. Sinnott). Two panoramic photos. Northern Belle and Holmes mines near center of right-hand picture.

The New Candelaria Mines Co. was formed about 1924 and it, too, leased the Argentum property. A little development and mining was carried on in the Northern Belle mine, but the company failed. The mill at Candelaria was closed in 1925, was apparently never again opened, and has since been removed. In 1927, the property was relinquished to the owner, the Argentum Mining Co.

Between 1915 and 1925, desultory efforts in the Northern Belle had largely consisted of mining remnants of oxidized ore. The deep levels had reached sulfides, which at that time were generally not workable. During 1925–1930, some sulfide ore of moderate grade was developed but up to this writing (1955) only a small tonnage had been mined.

A few individual miners attempted to make a living in the district from 1931 until 1942, but the mills had been shut down long since and the meager output of ore had to be hauled elsewhere for treatment. During World War II the water system disintegrated, Candelaria was deserted, the buildings fell to pieces, and the town virtually vanished from the face of the earth.

G. A. Peterson, in 1947, began a small but profitable operation at the idle Potosi mine near the west side of the district. At the time of this writing, he and 3 or 4 associates had continued successfully for seven years, accounting for most of the small output of the district during that period.

In 1950–1951, Newmont Mining Corp. lengthened an adit in barren volcanic rocks east of the Northern Belle mine, and attempted to locate ore beneath the volcanic section by diamond drilling. No further action has been taken.

The Argentum Mining Co., which holds title to the Northern Belle, Mount Diablo, and Lucky Hill mines, was purchased by E. S. Gates and C. E. Earl in 1951. They built a mill at Columbus salt marsh southeast of Candelaria, and have been experimenting with the treatment of sulfide ore and material of the mine dumps. They reopened the Northern Belle shaft in 1952, and expected to attempt underground mining in 1955, probably on the 15th, 16th, and 17th levels. The company hopes to recover the sulfide ore in the Northern Belle, and to treat some of the dump material of this mine and possibly the Mount Diablo and Lucky Hill mines. The mill will be prepared for an operation of 300 tons or more per day if the dump material can be successfully processed, but this remains to be seen.

The Argentum Mining Co. owns a large tonnage of old tailings produced by the milling of Candelaria ore at Belleville and at

Candelaria. During 1953 and 1954, a total of 8,575 tons of tailings was shipped from Belleville to the American Smelting and Refining Co. plant at Selby, Calif. The tailings are said to contain lead, as well as precious metals, and to be nearly self-fluxing.

SUMMARY OF PRODUCTION

The Candelaria district has yielded an important quantity of silver, and lesser amounts of gold, copper, lead, zinc, and antimony. A little nickel was produced in 1882 near Columbus, probably in the Candelaria district. Small amounts of barite, turquoise, variscite, and serpentine rock have been mined.

The total production, chiefly silver bullion, may have been worth $20 million (gross). However, this cannot be confirmed by published figures. The data available to the writer are listed by year in table 1. The statistics only account for a production of about $15,029,000 through 1954, but no figures are at hand for some years. Most gaps in the record indicate lack of activity in the district, but at times the mining companies apparently did not submit reports to the agencies compiling data. For example, after the Northern Belle mine was acquired by the Holmes Mining Co. in 1884 it continued to produce through 1891, but its contribution is not indicated in the annual totals for the district during most of that period.

The data are sufficient to show that the Candelaria district, chiefly because of the productivity of the Northern Belle mine, yielded more than $1,000,000 per year in bullion during six of the years between 1875 and 1883. In the first three quarters of 1875, the Northern Belle produced 6,982 tons of ore valued at $544,102 (Raymond, 1877, p. 134). In 1877, the same mine yielded $1,270,757, and its total output (mostly since 1873) approached $3,700,000 (Whitehill, 1879, p. 25). By the end of 1883 the Northern Belle had produced more than $10,000,000 in bullion and had paid $1,122,500 in dividends (Knopf, 1922, p. 18), without ever having levied an assessment. The Mount Diablo mine ranked second to the Northern Belle, but even at its height it produced only about eight thousand tons of ore a year. Knopf (1922, p. 19) notes that in 1883 the Mount Diablo sent 7,848 tons of ore to the mill, and that $441,518 in bullion was obtained from this; but in 1891, a total of 7,715 tons of ore yielded only $186,833, indicating that the grade had fallen one-half. The Lucky Hill mine has produced probably a little more than $1 million altogether. No estimate is available for the Potosi mine, which probably ranks among the first 3 or 4 properties in the district.

One of the factors in the decline of profitable production was an almost continuous decrease in the price of silver. The year's average London price (translated to dollars) was $1.328 per ounce in 1870. In 1875 it was $1.246; in 1880, $1.145; in 1885, $1.0648; in 1890, $1.046; in 1892, $0.871; and in 1900, $0.620. ("Report of the Director of the Mint Upon the Production of Precious Metals" . . . See volumes corresponding to the years mentioned.)

The small scale of the annual production of the district since 1891 is clearly shown in table 1. Apparently the only years in which the gross output exceeded $100,000 were in 1916–1917 when tailings were re-treated, and in 1923 when the Lucky Hill mine was revived. At times the combined efforts of several small operators brought only meager results; for example, in 1911 the grand total of 278 tons of ore was mined by six producers. Output during the past few years has been between 1,000 and 3,000 tons annually, valued at $20,000 to $100,000.

GEOLOGICAL WORK IN THE DISTRICT

Previous Studies.

J. E. Spurr included a brief note on the "Candelaria Mountains" in his compilation of the geology of Nevada south of the 40th parallel (Spurr, 1903, p. 113–114). His text, as well as plate 1 of this bulletin, indicate the formations near Candelaria were supposed to consist of Carboniferous strata, Eocene-Miocene strata, and fine-grained Tertiary volcanic rocks.

The earliest published geological report on the area as a mining district was prepared by Knopf (1922), who at that time was a member of the U. S. Geological Survey. Knopf had no opportunity for mapping, but his brief report is an excellent preliminary survey of the petrology and economic geology, and it includes the history of the district. In 1922 and 1930, J. A. Burgess studied the surface geology and made geological maps of some of the underground workings in the Northern Belle and Lucky Hill mines. This work, which has not been published, is in the possession of the Argentum Mining Co.

A reconnaissance of the Tonopah and Hawthorne quadrangles was made in 1922 and 1923 by Ferguson and Cathcart (1924), and detailed stratigraphic and paleontological work was begun by S. W. Muller in 1927. Muller and Ferguson extended their studies during subsequent years, and their publications include important observations and maps of the vicinity of Candelaria

TABLE 1—Production of the Candelaria mining district by years.

Year	Tonnage	Gross value (dollars)	Source of data[1]	Comments
1865	?	?	----------	Prospecting only.
1866	?	?	----------	Insignificant production.
1867	?	?	Raymond (1869)	Small production; small 4-stamp mill at Columbus.
1868	25	?	do	
1869	?	?	----------	
1870	9	762	Couch, Carpenter	
1871	864	134,609	do	
1872	2,927	146,852	do	
1873	2,905	250,461	do	Northern Belle, Holmes, and Mount Diablo mines.
1874	3,271	282,621	do	do
1875	12,237	910,905	do	Northern Belle mill started in March.
1876	24,716	1,424,175	do	Mostly Northern Belle (and Holmes).
1877	30,880	1,326,919	do	do
1878	7,502	301,362	do	do
1879	?	823,864	do	
1880	?	1,189,028	U. S. Treas. Dept.	$1,171,028 in silver, $18,000 in gold.
1881	?	1,237,869	Couch, Carpenter	
1882	36,509	1,372,228	do	
1883	27,601	1,205,457	do	Northern Belle, Holmes (?), and Mount Diablo.
1884	2,363	26,616	do	Mostly Mount Diablo; Northern Belle idle.
1885	14,464	497,958	do	Mostly Mount Diablo; Northern Belle production considerable, but not recorded.
1886	12,802	361,218	do	Mostly Mount Diablo, Georgine, etc. Northern Belle production probably considerable, but not recorded.
1887	10,693	313,676	do	do
1888	9,148	284,909	do	do
1889	12,365	279,411	do	do
1890	8,951	259,446	do	do
1891	20,496	548,440	do	Northern Belle (including Holmes), and Mount Diablo.
1892	115	9,200	do	
1893–97	?	?	----------	No production reported; probably small.
1898	181	22,640	do	
1899–1904	?	?	----------	do
1905	?	?	Mineral Resources of U. S.	Some production, largely from Georgine mine.
1906	?	?	do	Some production; Georgine and Humboldt mines.
1907	?	?	do	Some production; Humboldt Consolidated Mining Co.
1908	?	?	----------	Probably some production from Potosi mine.
1909	?	?	Mineral Resources of U. S.	Some production, Potosi (mine closed May 15).
1910	?	?	do	Small production, one mine only.
1911	278	5,876	do	Largely from Swastika mine.
1912	903	19,001	do	Largely Bi-Metallic mine (Swastika).
1913	2,262	27,049	Couch, Carpenter; Mineral Resources of U. S.	Lucky Hill, Mount Diablo, and Bi-Metallic mines, and re-treated tailings at Columbus.
1914	1,157	21,570	do	Lucky Hill, Bi-Metallic, Northern Belle, etc.
1915	?	90,124	do	Largely re-treated tailings at Belleville.
1916	2,130 ore; 39,431 tailings	172,219	Mineral Resources of U. S.	do
1917	5,032 ore; 39,176 tailings	276,635	do	do
1918	?	5,883	Couch, Carpenter; Mineral Resources of U. S.	Some tailings and ore from Lucky Hill mine.
1919	?	?	Mineral Resources of U. S.	Small production; Lucky Hill, Potosi, etc.
1920	?	?	----------	Probably little or no production.
1921	?	?	----------	do
1922	?	?	Mineral Resources of U. S.	Some production; Lucky Hill mine.
1923	87,234	369,712	Couch, Carpenter	Largely Lucky Hill mine; it then closed.
1924	?	?	Mineral Resources of U. S.	Some production from Northern Belle mine.
1925	23,127	?	do	Largely Northern Belle mine; mill closed in September.
1926–34	?	?	----------	Probably little or no production.
1935	1	512	Minerals Yearbook	
1936–37	42	711	do	Mostly from Secretary mine.
1938	80	1,047	do	
1939	3,725	41,796	do	Georgine, Lucky Hill, Hecla-Climax, Protection, Silver King, Silver Surprise mines.
1940	4,273	77,091	do	Mount Diablo, Silver King, Silver Surprise mines.
1941	1,805	40,131	do	Silver King, etc.
1942	957	25,375	do	
1943	55	2,642	do	
1944	?	?	do	Probably little or no production.
1945	1,507	19,617	do	Re-treated tailings.
1946	1,842	28,196	do	do
1947	1,446	29,087	do	Possibly tailings.
1948	2,175	87,548	do	Largely from (New) Potosi mine.
1949	877	48,448	(approx.)[2]	(New) Potosi mine.
1950	1,889	84,072	do	do
1951	1,218	59,138	Minerals Yearbook	do
1952	1,687	122,542	(approx.)[2]	do
1953	1,351[3]	85,176	do	do
1954	1,368[3]	74,288	do	do

Total recorded production $15,029,112.

[1]Refers to Literature Cited unless otherwise noted.
[2]Information from G. A. Peterson (personal communication, 1955).
[3]Tailings shipped from Belleville, 1953–54, not included above. About 8,575 tons was shipped to Selby smelter (E. S. Gates, personal communication, 1955). Value is not accurately known.

(Muller and Ferguson, 1936, 1939). The sedimentary units were defined in print for the first time, and the district became the type locality of the Candelaria formation of lower Triassic age. Later, Ferguson and Muller (1949) published a description of the exceedingly complex structure and tectonic history in the Hawthorne and Tonopah quadrangles. This was based upon field work carried on intermittently for many years. Recently, Ferguson, Muller, and Cathcart (1953, 1954) published geologic maps of the Coaldale quadrangle, just east of Candelaria, and the Mina quadrangle, which includes Candelaria. In the meantime, Barksdale (1949) studied the Tertiary volcanic rocks of the district as a sequel to his work with the Stanford Geological Survey.

Mapping by the Stanford Geological Survey.

Students and instructors of Stanford University field geology classes, composing the Stanford Geological Survey, mapped the Candelaria district by plane table in 1939, 1948, and 1949. Most of the actual plotting of geological features was done by students. The instructors planned and supervised the work. During each of the 3 years, 4 to 5 weeks were spent in the field, and 2 to 3 weeks in the office. The field periods were brief, but the man-hours of work were considerable. Each year, the field party consisted of 3 to 6 instructors and 20 to 40 students. Altogether, 10 instructors and 94 students participated[5].

In 1939 this Survey was directed by D. W. Lemmon, who was assisted by B. M. Page and F. R. Kelley. A triangulation net and elevations were established, and the geology and topography were mapped on a scale 400 feet to the inch. In 1948, the field party was directed by B. M. Page, assisted by J. D. Barksdale, F. R. Kelley, E. E. Roberts, E. F. Cook, and C. Webster. The geology and topography were re-mapped on a scale of 200 feet to the inch. In 1949 the Survey was directed by B. M. Page, assisted by F. R. Kelley, H. P. Schaub, C. V. Campbell, and B. W. Ryan; the northern two-thirds of the area was re-mapped.

The writer spent a few weeks in the field during 1952 and 1953 revising parts of the plane table map. The latter appears herewith as plate 1. Only a little underground mapping was done by the Stanford group. No attempt was made to carry out a complete petrographic study of the rocks, or a thorough laboratory examination of the ores.

[5] The following students worked on the project: W. A. Adent, R. M. Anderson, K. H. Arleth, J. Arneill, R. J. Aseltine, A. H. Balch, R. M. Bauer, J. M. Beall, R. H. Beggs, E. G. Belosic, C. B. Berry, F. A. F. Berry, R. G. Berry, A. E. Bradbury, D. W. Carlson, R. H. Carpenter, S. E. Clabaugh, R. D. Conrad, R. W. Constable, D. S. Costello, W. R. Davidson, F. A. Della-Rose, H. Dokuzoglu, R. C. Douglass, C. D. Erickson, R. B. Ferguson, R. D. Fitting, D. R. Forbes, W. D. Fritz, J. E. Frost, M. M. Glasser, F. R. Hall, E. L. Hamilton, C. L. Hicks, L. H. Hilpert, E. G. Hoskins, R. G. Hoyt, R. S. Johnson, V. C. Jones, R. J. Karren, C. F. Knutson, J. A. Kurfess, M. C. Lachenbruch, A. Lewis, J. L. Lewis, R. L. Liscomb, E. Magill, C. G. Maio, A. T. Mannon, E. L. Marier, W. E. Mattingly, F. A. Mau, B. D. McCreary, W. W. McDivitt, J. P. McLain, R. E. Miller, R. L. Myers, W. H. Myers, T. Off, J. L. O'Neill, F. Paguirigan, R. Phillips, H. B. Post, H. Ptasynski, J. I. Rael, J. L. Read, A. R. Robins, B. W. Ryan, A. F. Sanborn, N. E. Saunders, P. S. Shepardson, F. E. Smith, C. E. Smith, R. A. Smith, N. J. Silberling, H. R. Taber, P. K. Theobald, R. G. Thomas, H. J. Tillia, F. D. Trauger, R. E. Trefzger, J. W. Walker, K. G. Wallace, A. S. Walton, W. W. Whitley, W. A. Wickett, J. G. Wigmore, R. B. Willis, T. H. Willis, A. C. Wilckens, D. Wilson, G. F. Worts, T. S. Wyman, and H. C. Zwang.

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The students and instructors, who labored together to produce the geologic map, deserve all the credit for the field work. The author is most grateful to them. The previous studies of A. Knopf, J. A. Burgess, S. W. Muller, and H. G. Ferguson were invaluable to the Stanford group, and the personal advice of several of these men was likewise extremely helpful. The identification of certain minerals, fossils, rocks, and ores was aided by the skill and experience of S. W. Muller, R. R. Compton, F. R. Humphrey, D. E. Lee, and A. Knopf. The manuscript of this report was critically read by A. Knopf, S. W. Muller and H. G. Ferguson. The geologic map was expertly drafted by Mrs. Beverly Malarkey. The writer is sincerely appreciative of all the above-mentioned contributions, and others that are too many to enumerate.

It is a pleasure to acknowledge the privileges extended by the late Mr. Grube, of the Argentum Mining Co., and A. Nelson, E. S. Gates, and Carl Earl of the same company. The Stanford group is grateful for the cordial cooperation of G. A. Peterson, operator of the Mt. Potosi mine, and of several other individuals who gave permission to examine mining properties.

ROCK UNITS OF THE AREA

PALMETTO FORMATION (ORDOVICIAN)

The oldest formation in the district consists largely of chert, thin-bedded dolomite, and shale. These rocks are broadly distributed in the southeastern part of the district and along the south side of the Candelaria Hills. Ferguson, Muller, and Cathcart (1953, 1954) have extended to these rocks the name "Palmetto formation," a designation used by Turner (1902, p. 265) for somewhat similar strata farther south in the Palmetto Mountains of the Silver Peak quadrangle.

Chert and shale.—Chert predominates in the Palmetto formation of the Candelaria district. The prevalent type is gray to gray white, weathering tan gray. Black chert, probably colored by carbonaceous matter, also is abundant but red and brown varieties are less common. The chert layers are generally 0.5 to 4 inches thick, and are separated from one another by shale or slate intercalations 0.05 to 0.5 inch thick. The siliceous cherty beds are characteristically subdivided into small irregular prisms by closely spaced cross joints that are normal to the stratification. In some cases the fractures are healed by silification. Bedding surfaces are wavy, uneven, or humpy. The chief mineral of the chert is chalcedony, although an earlier opaline stage may be indicated by wavy "metacolloidal" banding in some specimens.

Dolomite and shale.—The Palmetto formation includes some dolomite, but this is neither as prominent nor as abundant as the chert. Dolomite composes part or nearly all of several members. The most common variety is originally gray, but it weathers to a warm orange-brown, unlike the more siliceous rocks. Individual strata are generally only 0.5 to 4 inches thick, and are separated from one another by shale or slate 0.1 to 4 inches thick. The shaly layers exposed in outcrops have acquired secondary lavender, pale gray, or tan coloration. The most common dolomite is fine-grained, ferruginous, and in most cases contains scattered fine quartz sand grains which are not in contact with one another. A lenticular, iron-free siliceous dolomite bed up to 24 inches thick was used to a limited extent as a marker bed in the southeastern part of the mapped area. It weathers to a pale gray color instead of orange-brown.

Stratigraphic relations and thickness.—The Palmetto chert, dolomite, and associated shale are well exposed (fig. 6), but are contorted, isoclinally folded, generally shattered, and cut by innumerable faults. Therefore no continuous stratigraphic section could be made. However, assemblages of strata can be identified from place to place within a limited distance. The following sequence of beds, recognized by J. L. Read, Jr., in parts of the southwestern portion of the mapped area, is an example:

	Feet
Gray chert and black chert, intimately associated	50+
Black chert in beds 2 to 6 inches thick	4
Orange-brown weathering dolomite with interbedded lavender weathering shale or slate	8
Gray, prominent chert in layers 2 to 4 inches thick, with a black layer at the top	5
Orange-brown weathering dolomite in beds 0.5 to 4 inches thick	20–100
Total	87–167

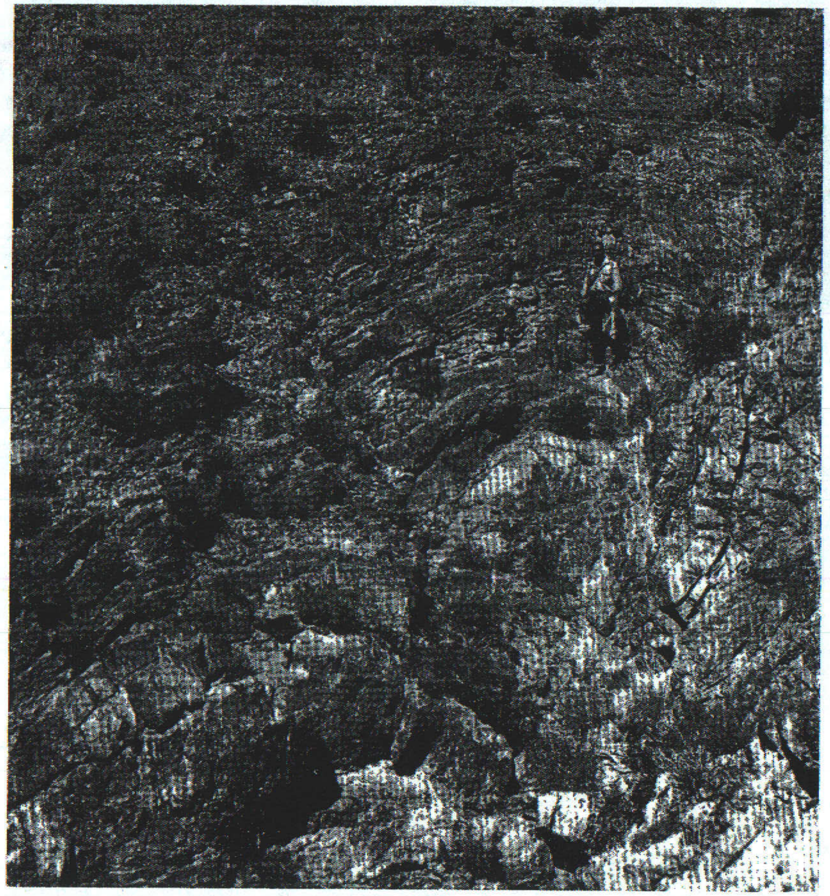

FIGURE 6. Palmetto formation (Ordovician). Exposure of chert showing contorted structure, southeast of Candelaria.

The total thickness of the Palmetto formation is unknown, as neither the base nor the top has been found. The upper part was eroded away prior to the deposition of the Diablo formation.

Ferguson, Muller, and Cathcart (1954) estimate that the thickness exceeds 4,000 feet in the western part of the Candelaria Hills, and such a figure seems plausible in the area of this report.

Fossils, age, and correlation.—These rocks are considered to be Ordovician on the basis of graptolites found by Ferguson and Muller in similar strata 7.5 miles west and 5 to 7 miles southwest of Candelaria. The graptolites are of Normanskill age (Ferguson, H. G., and Muller, S. W., personal communications, 1948–1952). Evidence as to age is scanty in the restricted terrain mapped. However, a 1-foot bed of lavender shale in the midst of a chert sequence 8,000 feet S37°E of Candelaria yielded several poorly preserved graptolites. These were identified by S. W. Muller, who noted a biserial arrangement of thecae resembling that of *Climacograptus*.

The writer and his associates found no other recognizable fossils in the Palmetto formation near Candelaria, except one-celled organisms in the chert. These, according to Thalmann (Thalmann, H. E., personal memo, 1953) vaguely show some sort of fine reticulation, and are probably radiolarians.

The surfaces of some chert layers show structures which superficially simulate fossils. One type of structure consists of convex humps of chalcedony, 0.5 to 1 inch in diameter and 0.1 to 0.3 inch high, generally occurring in groups of many individuals. Another type is suggestive of slender crinoid stems lying in the bedding plane, but segmentation is lacking. Neither type shows any definitely recognizable organic structure megascopically or in thin section, and both consist entirely of dense chalcedonic chert.

The Ordovician age of these rocks, and the presence of chert members, are the chief bases for correlation with the Palmetto formation. The Palmetto formation in the type locality is said to consist of Ordovician graptolite-bearing shale and argillite, plus chert with intercalated slate or shale. It is also said to contain rhyolitic tuffs and lavas (Turner, H. W., 1902, p. 265–266), but re-examination may show these igneous rocks to be felsite dikes and sills comparable to those near Candelaria.

DIABLO FORMATION (PERMIAN)

A thin grit or angular-grained sandstone overlies the Ordovician rocks, with angular unconformity ranging from 5° to 90° (fig. 7). This grit, together with thicker equivalents 5 to 10 miles north of Coaldale, has been named the Diablo formation (Ferguson, Muller, and Cathcart, 1953). The thicker parts of the Diablo

FIGURE 7. Diablo formation (Permian), here consisting of 25 feet of grit. Base of grit rests with angular unconformity upon dolomite and chert of Palmetto formation (Ordovician). Diablo formation is overlain (at man's feet) by Candelaria formation (Lower Triassic). Beyond the man, the section seen in the foreground is repeated by a fault. Locality is southeast of Candelaria.

formation east of the Candelaria district contain a good deal of dolomite (Ferguson, Muller, and Cathcart, 1954), but no carbonate facies was found in the area of this report. The explanation of the "Geologic Map of the Mina Quadrangle" (Ferguson, Muller, and Cathcart, 1954), designates type localities of the formation. The crest and west slope of Mount Diablo[6] and the hills to the west are the type locality of the sandstone or grit. The hills west of the road, a mile north of Columbus, are the type locality of the dolomite.

Lithology.—The grit composing the Diablo formation near Candelaria is well cemented, and forms rough, rather prominent dark brown outcrops. The component grains are subangular particles of chert and rounded particles of quartz, both constituents being 0.02 to 0.1 inch in longest dimension. Gray, black, and red chert grains of elongated shape predominate, and are obviously derived from the underlying Palmetto formation. The cementing material is quartz, and the rock tends to break across the sand grains when struck with a hammer. In many places there are transverse joints which have been filled with silica. The grit is generally about 10 feet thick, but in some localities it ranges up to 30 feet and in others it is entirely absent. Locally the grit contains sparse, small chert pebbles at the base, and the lithified basal gravel and sand fill crevices in the rocks of the underlying Palmetto formation. In places black flint nodules 0.5 to 1.0 inch in diameter occur at the very top of the unit, embedded in the grit.

Importance as a marker bed.—The Diablo formation is the most distinctive key bed in the Candelaria district, and fortunately is stratigraphically near the most favorable host rocks for ore deposits. It has been traced from the southeast corner to the northwest corner of the mapped area, appearing and reappearing in many fault blocks and folded structures. There is some likelihood of confusing this sandstone with a similar bed which occurs 50 to 150 feet higher in the section, within the Candelaria shale. However, the "upper grit" conformably overlies shale, whereas the "lower grit" (Diablo formation) typically rests discordantly upon chert.

Fossils, and stratigraphic status.—The following fossils have been recognized in the Diablo formation between Candelaria and State Highway 65 (Muller, S. W., oral communication, 1948):

[6]Called Candelaria Mountain in this report and in Knopf (1922). It is bounded by the Candelaria and Reservoir faults, and extends from the vicinity of the Potosi mine to Pickhandle Gulch (pl. 1).

Linoproductus phosphaticus Girty
Neospirifer pseudocameratus (Girty)
Punctospirifer pulchera (Meek)
Pugnoides osagensis var. *occidentalis* Girty
Chonetes sp.

These were found in fine grained, locally dolomitic sediments which lie to the east of the Candelaria district. Students working in the limited area of the present report also found some of the above listed forms, but only as rough molds, in the upper part of the grit. Muller considers the faunal assemblage to be Middle Permian.

CANDELARIA FORMATION (LOWER TRIASSIC)

Importance.—The Candelaria formation is exposed over a large part of the district, and the lower beds are the most important host rock for ore deposits. The formation was first described in print by Muller and Ferguson (1936, p. 243–244), who pointed out that it contains the earliest Triassic marine fauna recognized in North America. Part of the type locality is included in the map of the present report (pl. 1), being about 2 miles southeast of Candelaria townsite.

Lithology.—Muller and Ferguson (1939, p. 1582–1583) report that the lower part of the type section consists of 1,225 feet of shale with a few thin limestone beds and lenses, and that this is overlain by 1,000 feet of predominantly massive sandstone beds (perhaps locally tuffaceous), and that the sandstone is overlain by 1,000 feet of shale with a few beds of limestone. The reader should refer to the cited article for details. Apparently only the lower third of the section is represented in the area of the present report, as no massive sandstone is present there.

The Candelaria formation in the eastern part of the mapped area, including part of the type locality, is little affected by metamorphism and alteration. In the western part, especially near the mines, the formation is largely argillite and is locally hydrothermally altered beyond recognition. A comparison between the eastern and western lithologies is shown in table 2. The features italicized are useful in recognizing the parts of the column in which they occur, and some of those which are listed in the right-hand column are faintly perceptible even in moderately altered rocks near the mineral deposits.

TABLE 2—Comparison of sections of Candelaria formation.
(Lower part only.)

Section 1¼—1¾ mi. SE of Candelaria (Top not exposed)	Thickness (feet)	**Section ¼—½ mi. S and SW of Candelaria** (Top not exposed)	Thickness (feet)
Shale, olive-greenish-gray, *weathering olive-greenish-tan to tan.* Some is flaky, some is platy, but most breaks down into "pencils" (slender prismatic fragments). Hard, brittle.	725+	Argillite; greenish gray, weathering tan or greenish tan, dense; few or no laminations; no visible bedding; *plane joints and smooth joint surfaces.*	200+
		Argillite; greenish gray, with *1–3 tuffaceous (?) sandstone beds* about 1 ft. thick.	6–20
Shale; fissile and locally flaky; some weathers *lavender;* part of lower 60 ft. is originally black, calcareous, with abundant *Claraia;* middle part includes many concretionary lenses of limestone containing *Meekoceras.*	275+	Argillite; *varved,* weathering greenish-tan or light brown. Alternate laminae are dense, textureless; intervening *laminae grade from fine sand to fine silt;* many dull white angular grains may be volcanic ash. No tendency to split along bedding. Rock commonly cut by innumerable healed miniature faults.	100–300
		Argillite; gray, greenish-gray, or black. commonly with *white layers ⅛ in. thick.*	30
"Upper grit." *Sandstone, containing many chert grains;* similar to Diablo formation at bottom of section.	0–2	"Upper grit." *Sandstone, containing many chert grains* and locally some angular white fragments up to ¼ in. Brachiopod molds, especially near top. Locally prominent outcrops.	0–5
Shale; fissile, flaky to platy; gray, but commonly weathering *lavender; many black layers ⅛ in. thick, and flattened phosphatic (?) nodules* ½–1 in. long. 2–10 beds of black *dolomite, weathering mouse-gray, 4–30 in. thick;* 1 or 2 of these *near underlying sandstone contain black flint nodules.*	140–160	Argillite; gray to black, weathering gray to light brown, commonly with *white layers ⅛ in. thick, with a few flattened white nodules ⅛–1 in. thick.* Locally, at base, dolomite 4–20 in. thick, with flint nodules.	150–190
"Lower grit" (Diablo formation). *Sandstone, consisting largely of chert grains.* Molds of brachiopods near top. Generally *rests on chert, unconformably.* A valuable marker bed.	0–30	"Lower grit" (Diablo formation). *Sandstone, consisting largely of chert grains.* Molds of brachiopods near top. Generally *rests on chert, unconformably.* A valuable marker bed.	0–30

Stratigraphic relations.—In the description of the type section of the Candelaria formation, Muller and Ferguson (1936) chose as the base the beds immediately overlying the Permian grit, which has since been named the Diablo formation. The top of the Candelaria formation is concealed by later deposits, faulting, or intrusions.

Muller and Ferguson found a fossiliferous zone containing Lower Triassic (Scythic) species. The lower part of the zone is characterized by *Claraia stachei, C. aurita,* and *C. claraia.* The upper part contains cephalopods, including *Meekoceras lilangense* and *M. tenuistriatum.* Recent plane table measurements show that

the *Claraia* beds are 175 feet stratigraphically above the base of the formation as defined above, and that the *Meekoceras* beds are 270 feet above the base.

Muller and Ferguson believed that the underlying Permian grit, the Diablo formation, is separated from the Candelaria formation by an unconformity. The grit is locally discontinuous, and the faunas above and below the contact with the overlying shale seemed to indicate a time gap. However, conclusive evidence for an unconformity is lacking in the restricted area of this report. In this particular area, the grit probably could have been regarded as the basal bed of the Candelaria formation. Only remarkably uniform erosion could have left such a thin remnant (the Diablo grit) preserved over much of a relatively broad area. Moreover, a second, very thin (0.5 to 5 feet) grit bed of peculiarly similar lithology lies well within the Candelaria shale, 140 to 190 feet above the Diablo formation (fig. 8). Thus it would seem that the two grit beds belong in the same sequence of strata. The main difficulty is that the Diablo formation appears to be Middle Permian, whereas the shale of the Candelaria formation is Lower Triassic. If the grit could be regarded as Upper Permian, the apparent time gap might vanish.

ROCK COMPLEX OF PICKHANDLE GULCH

Obscure character.—The rocks of lower Pickhandle Gulch are well exposed on both sides of the canyon road near the Northern Belle mine, but they are difficult to identify. They are dark gray to gray-black where fresh, and greenish-gray to brown in outcrops. Monotonous in obscurity, diverse in detail, lacking obvious textures and structures, and consisting of microscopic mineral grains, they are not well understood. Various geologists have applied tentative field identifications such as "serpentine," "altered tuff," "breccia," "altered andesite," "fault zone rocks," "greenstone," or simply "altered rocks." It now seems likely that several of these designations are locally valid, but none gives a correct impression of the mass as a whole.

Recent study suggests rocks of Pickhandle Gulch are a complex consisting of: (1) Intensely sheared, locally brecciated, baked meta-sedimentary host rock, (2) sheared fine grained meta-dolerite intrusives, and (3) mixed material consisting of xenoliths in a dense igneous matrix. In mapping, it was only possible to distinguish between the first and second categories. The third group, mixed material, was lumped with either of the other two according to the apparent dominance or subordinance of meta-sedimentary material. It is difficult to distinguish between some of the sedimentary and some of the igneous rock, even microscopically, and it is, therefore, hard to see the relations and significant lithologic features in the field. A good deal of debatable interpretation is unavoidably mingled with the following descriptions.

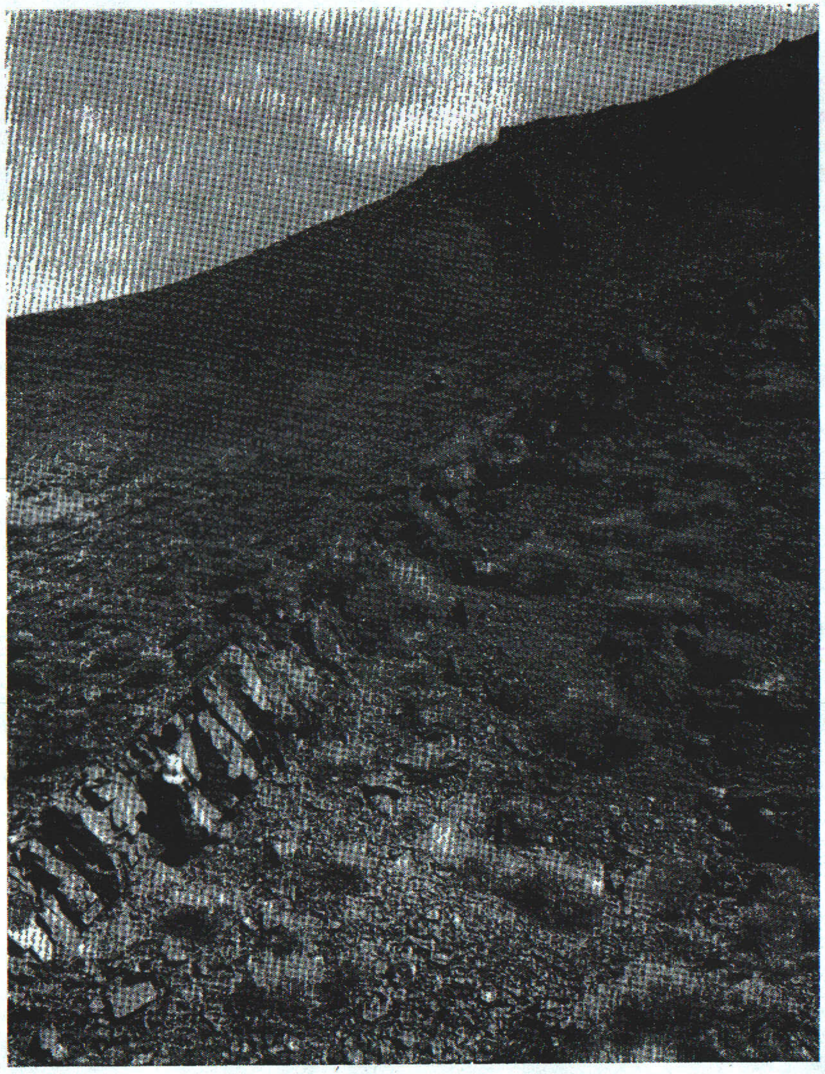

FIGURE 8. "Upper grit." A marker bed, here 4 feet thick, in the Candelaria formation. The same bed is visible in the distance, with different altitude, forming a wall-like outcrop. Near Potosi mine, west of Candelaria.

Meta-sediments.—The first of the principal constituents of the complex, the meta-sediments, are partially or entirely engulfed in the second constituent, the meta-dolerite. Some occurrences are island-like masses up to 300 feet in length, but others are merely small xenoliths. The larger masses are probably septa between intrusions, or pendants in intrusions. Boundaries between meta-sediments and adjacent meta-dolerite are vague to nonexistent, because on the one hand the host rock has been penetrated along every available crack by igneous material, and on the other the igneous material (meta-dolerite) is generally crowded with fragments of host rock. The original host rocks have been tortured and tormented, figuratively speaking, yet they have not reached a high grade of metamorphism in the usual sense, probably because the action took place at moderate depth. They have undergone preliminary crumpling and shearing, intricate igneous invasions, certain mineralogical changes, further shearing, hydrothermal alteration, local mineralization, and subsequent fracturing and shearing, until mere vestiges of original characters remain.

The smaller remnants of meta-sediments are unidentifiable flinty—or quartzitic-appearing silicified rocks. The ancestry of some can be guessed from the character of larger remnants, a few of which show original lithology and stratification.

Several of the identifiable "islands" consist of Candelaria shale and hornfels. One of these lies along a principal vein above the north end of the trestle high on the side of Pickhandle Gulch.

There are many remnants of quartzitic conglomerate and sandstone or quartzite, but rarely of limestone. These varieties may be seen along the 6,000-foot contour on the east side of Pickhandle Gulch 1,270 to 1,330 feet southeast of the Northern Belle shaft. At this locality the meta-sediments are in distinct beds 1 to 4 feet thick, separated at irregular intervals by intrusive meta-dolerite. One of the conglomerate remnants contains angular to rounded pebbles (1/8 to 8 inches in diameter) of black chert or flinty hornfels, gray chert, thinly laminated sandstone with much muscovite, shaly limestone, and hard, laminated, gray-black shale. Of these pebbles, the cherty varieties predominate. The stratigraphic unit of which the conglomerate, sandstone, and scanty limestone were once a part, is unknown.

Sandstone and sandy siltstone are represented in many metasedimentary remnants of obscure outward aspect. In the main adit (1,100 level) of the Holmes mine, the predominant rocks are megascopically unrecognizable, but under the microscope some of them show separate quartz sand grains or intact fragments of sandstone, the matrix in either case consisting of alteration minerals such as chlorite, sericite, carbonates, fine pyrite, and unidentified microcrystalline minerals. Some of the sandy rocks show S-planes defined by dimensionally oriented quartz grains, but these planes are masked by later shears and fractures and are best seen on artificially polished and oiled surfaces. The planes are invisible in outcrops and mine workings. A few specimens show local mylonitization.

Meta-dolerite.—The second principal constituent of the Pickhandle Gulch complex is meta-dolerite. It is an altered rock in which ophitic texture is preserved in small patches surrounded by sheared, less recognizable material. The original minerals have been partially or wholly replaced. They are represented by near-relatives and by pseudomorphous microcrystalline aggregates of later vintage. Apparently the chief original minerals were pyroxene and plagioclase. The latter occurred as a groundmass of microscopic laths and, in some cases, as tiny zoned phenocrysts. The pyroxene was about as abundant as the plagioclase, and formed stubby anhedral to euhedral grains of microscopic to megascopic size.

The plagioclase which remains at present has a low index of refraction, and apparently some of it is albite, but this is not considered to be the original variety. The major part of the plagioclase has disappeared entirely, owing to replacement by sericite and other microcrystalline minerals. The pyroxene, if it did indeed exist, has given way to a succession of later ferromagnesian minerals. Some meta-dolerite contains abundant green, shreddy hornblende with outlines suggestive of original pyroxene. Aggregates of microscopic actinolite have succeeded some of the hornblende, and actinolite needles extend even beyond the hornblende areas. In some of the meta-dolerite much of the hornblende has been altered to microcrystalline biotite and chlorite. Iron minerals, including ilmenite, are scattered through the meta-dolerite in numerous microscopic grains, and sphene and leucoxene also are present.

Xenoliths are a characteristic feature of the meta-dolerite, and they occur in great profusion. However, they are not everywhere conspicuous, and many of them resemble the igneous matrix in color. They include innumerable small, angular, flint-like fragments measuring 0.2 to 4 inches across. Some of these are probably pieces of Palmetto chert, but most are bits of baked and

silicified Candelaria shale, almost indistinguishable from chert or flint. Other types of xenoliths are plentiful also. Some are faintly perceptible, greenish-gray, finely banded angular fragments 0.2 to 0.5 inch across, consisting of secondary silicate minerals.

SERPENTINE

Minor occurrences.—A few serpentine lenses, up to 220 feet in length, are isolated in the Pickhandle Gulch complex. Masses of serpentine were encountered underground in the Northern Belle workings. Serpentine in more restricted, narrow zones is found here and there in shear zones in the meta-dolerite. Relict textures suggestive of former serpentine have been noticed in some of the completely altered rocks in mineralized areas.

Principal serpentine mass.—The major body of serpentine form an east-west belt more than 6,800 feet long and 300 to 1,350 feet wide at the ground surface. This is believed to be the largest serpentine body in Nevada, and is undoubtedly broader at depth than at the present level of erosion. The mass as presently exposed is an elongated sliver bounded by faults on at least one side. The faulting permitted uplift and exposure of part of the serpentine, but presumably left an adjoining part of the serpentine body at depth, where it has not yet been uncovered. Consequently, the original shape of the mass is unknown. It may, however, have had an original east-west elongation, as the prevailing easterly strike of the older rocks probably influenced the pattern of intrusion.

The serpentine is, for the most part, dark green, but it ranges from black to bright pea-green. The color is locally varied because of alteration and weathering, so that bleached gray-white patches and rusty orange-brown areas are commonplace. Convex slickensided surfaces, irregular talcose shear zones, and other typical serpentine structures and textures are prevalent.

Origin and age.—Some of the serpentine was derived from ultrabasic rocks of granitoid texture, but some developed from relatively fine-grained basic rocks. The first-mentioned derivation is indicated by a few occurrences of bastite of granitoid dimensions, and is further supported by the local presence of chromite in grains several millimeters across. The derivation of some of the serpentine from doleritic rocks is indicated by apparent gradations into meta-dolerite in the terrain of the Pickhandle Gulch complex.

The serpentine is older than the numerous felsite dikes, which are themselves pre-mineral, yet the serpentine contains inclusions of the Lower Triassic Candelaria shale. The igneous rocks from which the serpentine originated are probably contemporaneous with the basic rocks of the Pickhandle Gulch complex, and may have stemmed from the same source. Possibly all are remotely related to the basic intrusives and extrusives described elsewhere (Muller and Ferguson, 1936, 1939, and Ferguson and Muller, 1949) in the Middle Triassic Excelsior formation.

Alteration.—Intense alteration of parts of the serpentine is ascribed to hydrothermal action immediately preceding mineralization, and will be described in a later section. However, an unrelated, earlier type of alteration has affected the rock 600 feet northwest of the Mount Diablo shaft. The serpentine has been converted to a white tremolite-talc rock which is exposed in an area of several thousand square feet. This mass of hydrous magnesium silicates may have approximately the same bulk chemical composition as the serpentine, except for a greater lime content. Vermiculite is scattered in narrow discontinuous streaks within the border zone of the tremolite-talc rock.

BASIC DIKE ROCKS

Basic rocks, other than the meta-dolerite and serpentine described above, are present, although not in abundance. All are undoubtedly pre-Tertiary, being more affected by alteration and deformation than the Tertiary rocks in the vicinity, but the exact ages are unknown.

Diabase.—Intrusive rocks, called diabase for want of a better name, are well exposed in the Palmetto formation 8,500 feet south of Candelaria (see map, pl. 1). The diabase is dark greenish gray and weathers brown. It is not homogeneous, relatively coarse varieties being interspersed with fine-grained varieties within a single mass, more or less in the manner of composite intrusions. In places the fine-grained facies forms angular blocks within the coarser variety. The diabase is almost 100 percent altered, probably deuterically, and original lath-like crystals are only faintly suggested by microcrystalline pseudomorphs. The minerals, in order of abundance, are chlorite, albite in fine aggregates, calcite in many scattered patches, and sphene.

Miscellaneous basic dikes.—A younger, smaller dike of basalt or dark andesite cuts one of the masses of diabase described above. Other small basic dikes occur at fairly wide intervals in the Palmetto and Candelaria formations. Most of them are less than 5 feet wide, and not all were mapped. Where weathered, many of these small intrusions are olive green or greenish brown.

ACIDIC TO INTERMEDIATE DIKE ROCKS

The large number of acidic to intermediate dikes is a prominent feature of the Candelaria district. The lithologic types are numerous, but only the principal varieties will be described here.

Felsite dikes.—The most abundant dikes in the district are felsite. Most of them are nearly white, except where stained by iron oxide, and show no mineral grains recognizable megascopically. These dikes are highly irregular in detail, but they fall into a striking pattern when considered in general plan (pl. 1). Underground the felsite is distinguished from other rocks, except white argillite, by the color and by the joints. The joints are more nearly planes than those of the Pickhandle Gulch complex and serpentine, and are more widely spaced than those of the chert and shale.

The average felsite, when viewed in thin section, is found to consist largely of sericite and fine quartz. Specks of pyrite, and tiny rosettes of extremely fine, dark tourmaline are commonly present. Relict aphanitic porphyritic texture and remnants of original minerals in some specimens indicate that much, and perhaps all, of the felsite is a petrologic facies of the quartz monzonite porphyry described below. Some may have been a fine textured equivalent of the porphyry, but some appears to be felsitic merely because of the development of microcrystalline alteration minerals and the consequent vanishing of original phenocrysts.

Quartz monzonite porphyry dikes.—Quartz monzonite porphyry was recognized in the district by Knopf (1922, p. 8), who says, "The least altered porphyry . . . contains numerous porphyritic crystals of feldspar and biotite and a few of quartz. Under the microscope the feldspars are seen to comprise both orthoclase and plagioclase, which are set in a microgranular groundmass. . . ." The phenocrysts are 1 to 2 mm long. The groundmass is locally variolitic and contains exceedingly minute incipient euhedral crystals which are probably albite. A prominent quartz monzonite dike 70 to 180 feet wide and 400 feet long occurs about 1,000 feet east of the Mount Diablo shaft. The dikes near the barite mine (pl. 1) are partly altered equivalent rocks.

Quartz diorite porphyry, etc.—A dike or other body just beneath the Quaternary basalt capping 1,150 to 1,450 feet southwest of the Northern Belle shaft appears to be quartz diorite porphyry. It contains andesine, biotite, and hornblende phenocrysts—all 1 to 2 mm long. These are set in a groundmass of microscopic andesine laths and fine quartz. The rock is partly sericitized.

Another variety of porphyry with feldspar and biotite phenocrysts in an aphanitic groundmass form 2 to 3 dikes in Pickhandle Gulch.

Other dikes consist of microtonalite. They are rather dark, and are finer grained than the quartz diorite porphyry, but may be related. An example of this type is 225 feet south of the Northern Belle shaft. It consists of tiny calcic andesine laths, interstitial quartz, and small phenocrysts of biotite and andesine. It is possible that the quartz and biotite are secondary, in which case the term "microtonalite" would not apply.

Age relations of the dikes.—All of the acidic and intermediate dikes whose age relations are known are younger than the basic rocks of the Pickhandle Gulch complex and the igneous forebears of the serpentine. They are pre-mineral and obviously unrelated to the Tertiary effusive rocks, which are post-mineral. Probably they are late Jurassic, or Cretaceous in age. An appreciable span of time may be represented, as it is unlikely that so many varieties of igneous material were introduced nearly contemporaneously.

CENOZOIC VOLCANIC ROCKS

Distribution.—Tertiary and Quaternary volcanic rocks, essentially unaltered and unmineralized, lie unconformably upon the deformed and locally mineralized pre-Tertiary formations. Doubtless the entire district was at one time heavily blanketed, but erosion has removed part of the volcanic cover, leaving thick remnants here and there. Not all of the extrusive rock units were laterally persistent, so the volcanic section differs from one end of the district to the other. Moreover, different segments of the column are preserved in the various remnants, and it is not everywhere possible to determine chronological relationships of separate segments.

The thickest Tertiary volcanic section exposed in the mapped area is 1½ to 2 miles southwest of Candelaria. A lesser, somewhat different, Tertiary volcanic section is 1½ miles southeast of Candelaria. Thin Quaternary basalt is widespread, north, west, and southeast of Candelaria (pl. 1), resting unconformably on Tertiary volcanic rocks and Mesozoic formations.

Volcanic petrology.—Some of the volcanic rocks were described by Knopf (1922, p. 8–12); these and others were later mapped by Stanford University students. Three students, E. L. Hamilton, B. W. Ryan, and J. P. McLain, made the southwest part of the map (pl. 1), which shows the best volcanic section. A petrographic study was carried out by Prof. J. D. Barksdale, who served on the instructional staff during the field work of 1948. His data are unpublished except in outline (Barksdale, 1949), but were generously made available in manuscript form to the writer.

The Tertiary volcanic column 1½ to 2 miles southeast of Candelaria is more than 2,000 feet thick, with several structural and erosional gaps. The petrology, summarized from Barksdale's unpublished work, is indicated in figure 9, and the areal distribution of the rock types is shown in plate 1. The lower part of the section consists of about 700 feet of nearly white dacitic tuffs. These are divided into four mappable units in plate 1, designated Tv-1, Tv-2, Tv-3, and Tv-4, respectively. Well-rounded pebbles, cobbles, and boulders locally lie at the base of tuff Tv-1, and between tuffs Tv-1 and Tv-2. A remarkable "pseudovitrophyre" (Tv-5), resembling obsidian with phenocrysts, forms a discontinuous dark layer 0.5 to 10 feet thick, above unit Tv-4. Elsewhere in the district it rests upon slightly different dacitic tuffs. It is interpreted as a welded vitric tuff formed by a nuée ardente type eruption (Barksdale, 1949). A prominent cream-colored rhyolite flow (Tv-6), lies upon the "pseudovitrophyre" and seems to have caused the welding of that unusual rock. The rhyolite is jointed in an imperfect columnar pattern, and composes a single flow 300 feet thick. Above it is rhyolitic tuff (Tv-7).

Hypersthene basalt flows (Tv-8), aggregating more than 200 feet in thickness, immediately overlie the acidic extrusive rocks just described. The basalt forms a conspicuous dark capping on several hills, contrasting with the underlying white tuff (fig. 10).

The succeeding rocks are separated from the hypersthene basalt by faults and concealed zones. The next unit shown in figure 10 and plate 1 is rhyolitic tuff (Tv-9, but originally there may have been intervening rocks between it and the hypersthene basalt. A thin basalt (Tv-10), containing olivine and augite, and attaining a thickness of only 30 to 40 feet, overlies tuff Tv-9. Above this is a sequence of dacitic tuffs, dacitic welded tuffs, and dacite flows, collectively more than 315 feet thick. In plate 1, these rocks are designated Tv-12, Tv-13, Tv-14, Tv-15, and Tv-16. The units numbered Tv-14 and Tv-16 are strongly banded, have a platy structure, contain discontinuous streaks of black glass, and are thought to be flows.

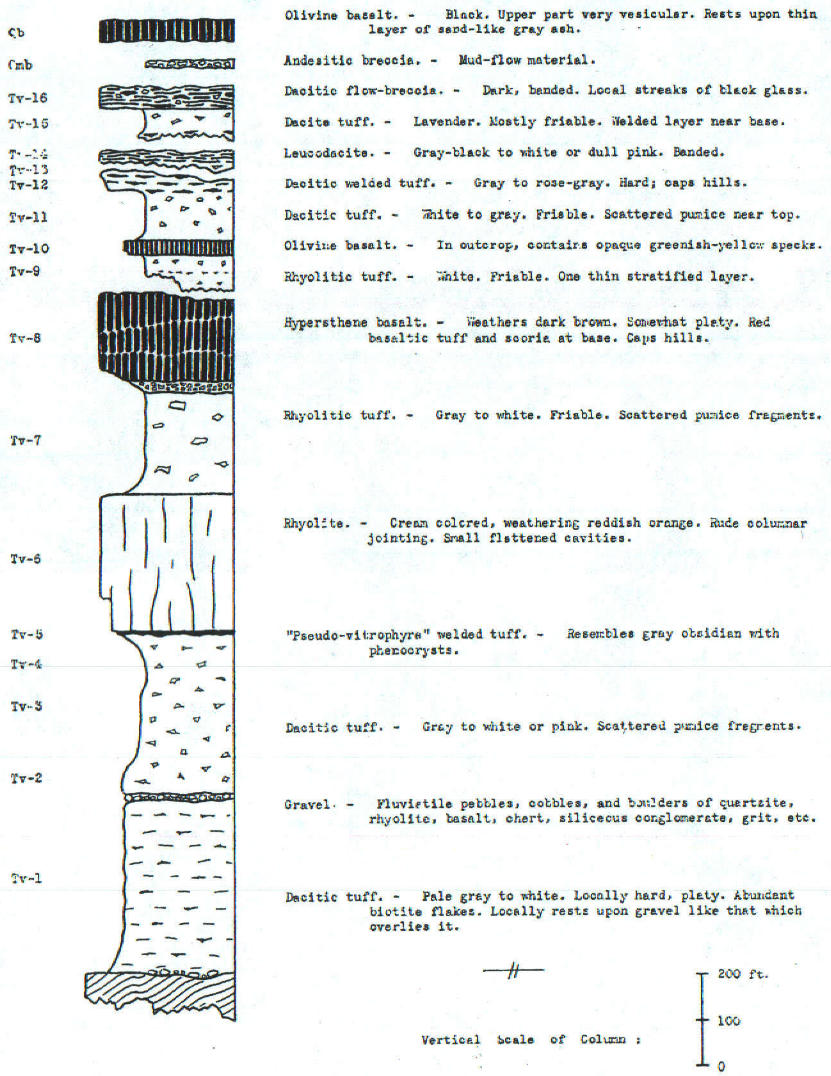

FIGURE 9. Columnar section of volcanic rocks southwest of Candelaria. (Symbols at the left refer to geologic map, pl. 1.)

The Tertiary volcanic column in the east part of the district is different in detail from the section (described above) in the southwest sector, and the two columns have not been successfully correlated. Although the symbols Tv-17, Tv-18, Tv-19, and Tv-20 in the east part of the map (pl. 1) are numerically higher than the designations of the rocks in the southwest part, there is no

FIGURE 10. Tertiary volcanic rocks south of Candelaria. Sections rest unconformably upon Palmetto formation (right), the contact being at the boundary of the gray terrain on the right and the white near the center. The lowest white members are dacitic tuffs. The pair of dark bands in the nearly white slope mark the top and bottom of a columnar rhyolite flow designated by "Tv-6" on the geologic map. The black rock unit on the left is hypersthene basalt, designated by "Tv-8" on the map. Two normal faults cross the view from left to right, dropping the nearer volcanic rocks with respect to those in the distance.

assurance that this correctly represents the age relations. Some tuffs (Tv-x) were not fitted into any column. The east volcanic section contains dacitic tuffs and welded tuffs, and a columnar flow of dacite or rhyolite (Tv-18). Overlying a dacitic tuff (Tv-19) unconformably, there is 25 feet of conglomerate, 25 feet of basaltic breccia and scoria, and 20 to 50 feet of olivine basalt which is texturally unlike any other basalt in the district. The conglomerate and basaltic rocks are mapped together as Tv-20 in plate 1.

A Quaternary (?) andesitic mudflow breccia (Qmb) unconformably overlies the Tertiary volcanic rocks, both in the southwest and in the east part of the district. The breccia consists of angular boulders, cobbles, and pebbles of andesite or light colored basalt in a fine grained matrix. It is spread over an eroded surface which truncates many of the older volcanic rocks.

Quaternary olivine basalt (Qb) covers some of the area as a nearly horizontal sheet. Typically, it is separated from the underlying rocks by 1 to 5 feet of loose, dark gray ash with a sandy texture. The basalt is commonly 25 to 75 feet thick, is columnar in part, and is vesicular in places. It is black on exposed surfaces, whereas the hypersthene basalt (Tv-8) weathers brown.

In resumé, the Cenozoic volcanic rocks comprise a predominantly acidic sequence interrupted by 3 or 4 basalts. The acidic rocks include several flows, but are largely tuffs and welded tuffs produced by explosive eruptions. The basalts, on the other hand, are mainly lava flows. They were not preceded by transitional extrusives chemically intermediate between dacite and basalt. Instead, they abruptly and incongruously appeared between rhyolitic and dacitic outbursts. A possible exception to the lack of transition may be represented by the Quaternary (?) andesitic mudflow breccia, which antedates the Quaternary basalt.

Unconformities in the volcanic section.—Discordant relationships between some of the tuffs may represent appreciable intervals of erosion, or may simply indicate inequalities in successive accumulations of ash from volcanic centers that were variously located. On the whole, there is little evidence for major unconformities within the main part of the volcanic section, but two marked unconformities appear near the top.

One of the two undoubted unconformities is between the upper acidic extrusive rocks and the overlying andesitic and mudflow breccia. The andesitic mudflow breccia occurs in nearly horizontal patches resting discordantly upon a variety of tilted dacitic tuffs and flows.

The other striking unconformity in the volcanic section is at the base of the youngest flow, the Quaternary olivine basalt. The latter is relatively flat-lying and broadly distributed. Apparently the andesitic mudflow breccia was largely eroded away before the outpouring of the olivine basalt.

Age of the volcanic rocks.—As implied above, the volcanic rocks are considered to be Tertiary and Quaternary. These age assignments seem reasonable, but no strong paleontological support is available. The rhyolitic and dacitic tuffs, 2 miles southwest of Candelaria, locally contain silicified wood of *Pinus* sp., kindly identified in 1955 by Virginia M. Page. The Newmont Mining Co. discovered a bone fragment in tuff about three-fourths of a mile east of Candelaria, but the bone is not diagnostic, although probably mammalian, according to V. L. VanderHoof (personal communication). No other fossils have been reported.

The acidic tuffs and flows (and intercalated basalts) are assumed to be Tertiary because they are somewhat similar in lithology and degree of deformation to Tertiary rocks in various other districts of western Nevada. They are structurally more disturbed than most Pleistocene formations of the region.

The andesitic mudflow breccia, which antedates the latest basalt, may be either Late Tertiary or Early Pleistocene.

The writer considers the late olivine basalt to be Pleistocene. The flows are warped, faulted, and cut by fairly deep canyons such as Pickhandle Gulch. However, they are not strongly folded, and they still cover broad, relatively flat areas of the ground surface. There is no evidence that any later formation, other than alluvium, has covered the basalt. If a superjacent formation ever existed and was stripped away, the stripping was remarkably precise, as the original surface features of the lava are well preserved. Moreover, modified remnants of a small basaltic cone may be seen 1 to 2 miles west of Candelaria, and the surrounding basaltic lava is obviously related to the cone. The latter could not be older than Pleistocene, judged by the modest degree to which it has been eroded.

Importance with regard to mining.—The volcanic rocks are clearly post-mineral, but their practical importance should not be overlooked. Some of the units are excellent structural reference planes. The latest basalt, in particular, strikingly reveals recent faults and thereby serves as an indicator of certain displacements of veins.

Future mining exploration may have to take into account the great thickness of barren tuffs and flows which would have to be

›enetrated in some places before a drillhole or shaft would reach nineralized formations. This probability would apply to the plain ıpon which the townsite of Candelaria is situated, where drilling night be contemplated to intersect ore bodies downfaulted from he main mass of Candelaria Mountain.

GEOLOGIC STRUCTURE

The structures and tectonic events will be discussed in the order f their development. For convenience, they are grouped in hronological categories which appear as headings below. However, the categories are somewhat arbitrary. Doubtless several ectonic episodes are crowded into each of the earlier ones, vhereas relatively minor deformations are singled out for each of he later categories because the latter part of the record is clearer.

EARLY FOLDS AND FAULTS IN THE PALMETTO FORMATION (POST-ORDOVICIAN, PRE-MIDDLE PERMIAN STRUCTURES)

The oldest structures were produced before the deposition of he Permian Diablo formation, which rests discordantly upon runcated strata of the Palmetto formation (Ordovician).

The Palmetto rocks are faulted at close intervals and are tightly olded. Seen from a distance, in some places they appear to dip omoclinally; that is, certain hillsides show broad bands of subued color which appear to be traces of north-dipping strata. 'his is partly illusionary, however, because many of the bands f color are surface expressions of shear zones and isoclinally olded members. The rocks are so broken by faults and ill-defined ones of shattering, individual folds are mappable in only a few ›calities.

In the southeastern part of the Candelaria district the prevailıg strike of the older structures is east to east-northeast and the ips of both upright and overturned strata are predominantly to ıe north, with countless local variations. In the west part of the ıapped area some of the chert of the Palmetto formation strikes orthwest or even north, and the dips in such cases are commonly, ıt not invariably, to the east. These trends do not prevail regionly, according to maps of other nearby districts (Ferguson and [uller, 1949, figs. 7-10).

The strike of beds and axes varies so much from one place to ıother there is a strong likelihood several episodes of folding ›ok place and that successive forces acted in different directions. here was ample time (Ordovician to Permian) for a complicated

series of events. Later, the structures were both intensified and modified by the superposition of post-Triassic folds and faults. Some of the folds were originally overturned farther than at present, as the several post-Triassic orogenies tended to raise upright some of the recumbent folds in the Palmetto formation south of Candelaria. This may be visualized by "undoing" the post-Triassic tilting (see cross sections, pl. 1).

MAJOR DEFORMATION OF TRIASSIC ROCKS (POST-TRIASSIC, PRE-TERTIARY)

After deposition of the Triassic sediments, the formations were tilted northward until the Triassic beds were inclined 20° to 60°. The dips were subsequently steepened, during the Cenozoic. The tilting took place along an east-west axis, and presumably was a local manifestation of large scale folding. Probably an anticlinal crest lies south of the present exposure of Triassic rocks, and a synclinal trough lies north of the Candelaria Hills. According to this supposition, the Triassic rocks of the Candelaria district constitute a single north-dipping limb of a major fold, which is otherwise concealed by Tertiary volcanic rocks and Quaternary alluvium.

Shearing, and perhaps actual thrusting, affected the rocks now exposed in Pickhandle Gulch. Some of the disturbance occurred before, and some after, the intrusion of dolerite. The Palmetto formation and Candelaria shale were locally contorted and brecciated, and possibly some of the "foreign" masses of rock (conglomerate, quartzite, and small amounts of limestone) may have been brought in by a thrust which grazed the present area of Pickhandle Gulch. The disordered and highly fractured material was then intruded intricately by subsilicic magma represented by meta-dolerite. Intense shearing followed the intrusion, leaving its impression upon the texture of igneous and host rocks alike.

Intrusion of peridotitic magma, which led to the development of serpentine, presumably took place during or shortly after the tectonic events just described.

FISSURES OCCUPIED BY DIKES (POST-TRIASSIC, PRE-TERTIARY)

The dikes of acidic and intermediate composition occupy fissures which are arranged in a rather systematic pattern. In plan, the pattern has three directional elements: N45°E to N65°E, N40°W to N65°W, and approximately east-west (pl. 1).

The dikes which strike nearly east-west are generally wider ıan the others. It is assumed that they occupy tension fractures, 'hich might have resulted from arching of the rock mass along n east-west axis. An underlying, elongated intrusion may have rovided both the arching and the dike-forming magma, which fected the simultaneous opening and forcible filling of the ssures.

PRE-MINERALIZATION REVERSE FAULTS
(POST-TRIASSIC, PRE-TERTIARY)

Reverse faults and small-scale thrusts displaced the Triassic nd older rocks after the intrusion of the dikes. These faults are ot occupied by igneous bodies. They are displayed particularly ell in the several places where the Diablo formation is repeated : faulted out. Most of the faults strike west or west-northwest, ut there is little uniformity in dip. Some dip toward the north, nd some toward the south. The north dipping faults, where :eeper than the beds, effect the repetition of strata; but where ss steep than the beds, cause omission of strata (see cross secons, pl. 1). Some of the reverse faults are almost parallel with ıe strata, and are best recognized where mineralized.

The north-dipping faults which are occupied by most of the eins of the district are probably reverse faults related to those escribed in the preceding paragraph. Some are bedding faults ı north-dipping Candelaria shale. Others, with similar attitudes, :cur in completely altered rocks without bedding. A few of ıe north dipping vein-faults are offset by slightly later preineralization fractures, but the great majority of later fractures 'e clearly post-mineralization.

The veins are described more fully in a later section.

POST-MINERALIZATION FOLDS
(EARLY PLEISTOCENE?)

After the deposition of ore and a subsequent interval of erosion, ertiary volcanism buried the older rocks beneath a thick mantle ' ash and flows. The volcanic centers are outside the mapped 'ea, and their structural situation is unknown.

Mild folding disturbed the Tertiary volcanic rocks, but some its effects are difficult to distinguish from tilting which accomınied later block faulting. A faulted, open syncline striking eastırtheast is prominent in the terrain of acidic tuffs in the east ırt of the area north of the serpentine belt. This fold has resulted om compression in an approximately north-south direction.

OLDER NORMAL FAULTS
(EARLY PLEISTOCENE?)

En echelon northeast-southwest faults.—Southeast of Candelaria, 4 or 5 en echelon normal faults offset the Diablo formation and adjacent rocks. The faults strike northeast, but lie in a northwest-trending belt. Most of them dip 50° to 70° SE. Only two of the faults are within the mapped terrain, but these two are conspicuous in the southeast quarter of the area covered by plate 1. They both display a wide zone of shearing and brecciation between rather distinct hanging wall and footwall surfaces. One is marked by a shear zone that is 90 feet wide at a locality 9,200 feet southeast of Candelaria. The other shows a 140-foot shear zone in exposures 6,800 feet southeast of Candelaria. One of the two faults has a throw of about 700 feet, and the other probably has a greater amount. Surprisingly, both faults die out along the strike within 2,000 feet of the localities where displacement is greatest.

East-west normal faults, and related structures.—Among the major faults of the district are some which strike east-northeast to east-west, and show normal displacements. These include the prominent Candelaria fault, which dips north and bounds Candelaria Mountain on the north, and the Reservoir fault, which dips in the opposite direction and which lies along the south margin of the mountain. These two faults have had complex histories, some of the movement having occurred before the outpouring of Pleistocene basalt, and some after this event. Both the old and young features of the faults will be described together in another section, in connection with "Basin and Range" faulting.

In addition to the two east-west faults cited above, there is another which perhaps originated at about the same time, but which has had no recent activity. This one dips north and forms the north boundary of the main serpentine mass for more than a mile. The serpentine mass has been uplifted, relatively speaking, against Tertiary volcanic rocks. The fault is offset in 2 or 3 places, but it can be followed westward toward Pickhandle Gulch. There it may be represented by a north-dipping fault which passes close to the Swastika shaft. This fault and a south-dipping parallel fault bound a conspicuous wedge of white Tertiary tuff on the east side of Pickhandle Gulch (fig. 11).

If the east-west faults existed at the time of the en echelon northeast faulting, possibly they have a strike slip component, but this has not been demonstrated.

FIGURE 11. Looking southeast across Pickhandle Gulch south of Candelaria. White Hill at left is Tertiary tuff, which forms a wedge bounded by normal faults dipping toward each other. Rock on both sides of tuff is serpentine, but hills in distance and at right center are underlain by Candelaria formation. Mount Diablo mine is marked by large dump at right; Princess shaft is at small white dump slightly left of center.

"BASIN AND RANGE" FAULTING
(INCLUDING LATE PLEISTOCENE—RECENT)

The normal faulting described above subsided temporarily, and an erosion surface of low to moderate relief developed. This surface was flooded by olivine basalt at some time in the Pleistocene. Block faulting was then renewed, and has apparently persisted to recent times. Some of the vertical displacements are precisely recorded by the thin basalt flows.

The Pleistocene and Recent movements, and probably some of the earlier ones, coincide chronologically with much of the "Basin and Range" faulting that characterizes the province in which the Candelaria district is situated. The recent faulting near Candelaria is, in fact, "Basin and Range" faulting, but it is atypical because it has taken place along east-west and east-northeast faults.

The Candelaria Mountain horst.—The most striking product of the "Basin and Range" faulting at Candelaria is the small, narrow, east-northeast horst bounded by the Candelaria and Reservoir faults (pl. 1). The horst comprises Candelaria Mountain. This block merges in a subtle manner with the sprawling bulk of the Candelaria Hills lying to the southwest, south, and east, the major part of the hills being less clearly defined and lacking marginal fault scarps. The Candelaria Mountain horst is only about 2 miles long and 1,500 to 2,400 feet wide. The boundary faults are marked by fresh scarps, but the scarp of the Candelaria fault is higher and steeper than the other. The scarps are dissected by steep-sided ravines, the mouths of which are separated by faceted spurs. The two marginal faults date back to the pre-Quaternary movements, but have been revived in geologically recent times. They appear to have a complicated history.

The Candelaria fault.—The north slope of Candelaria Mountain is bordered by talus cones rising 100 to 300 feet above the plain. These cones are surmounted by the scarp of the Candelaria fault, the scarp rising another 150 to 400 feet (fig. 2). In many places the surface juncture between talus material and bedrock marks the trace of the fault, and the hanging wall at this level is talus material consisting of basalt blocks partly cemented by calcium carbonate caliche.

The fault plane is exposed in ravines, prospect pits, and mine workings. Measurements of dip at the surface, recorded from west to east, are as follows: 66°, 62°, 70°, 75°, 56°, 75°, 61° 52°, 56°, 40°. The average of these figures is a little more than 61°.

his is in harmony with observed and computed dips of normal ıults as summarized by Hubbert (1951). In most places the ıult consists of 20 to 40 feet of sheared and granulated material ɔnfined between rather distinct hanging wall and footwall surıces.

This fault is believed to cut off one or more of the veins in the eeper levels of the Northern Belle mine. However, the Candeıria fault zone itself is mineralized farther west, and contains ɔme of the principal veins of the Georgine mine, Western tunnel, nd Vanderbilt tunnel. The mineralized part is presumed to be re-Tertiary, because the Tertiary volcanic rocks are unaffected y hydrothermal action. Therefore part of the Candelaria fault is ld, and was simply taken over by post-mineral movements.

Probably there were post-mineral movements both before and fter the outpouring of the Pleistocene basalt, but only the latter fects are readily measurable. The nearly horizontal basalt flows re offset a vertical distance of 600 to 800 feet in the territory etween the Georgine mine and the main Holmes adit. East of ickhandle Gulch the displacement of the basalt gives way to a ıonoclinal flexure in which the lava flows are draped like an ıclined sheet over the mountain front for a short distance.

The dislocation of the Pleistocene basalt is certainly not a true ıeasure of the much greater cumulative displacement of the older ɔcks. The vertical offset of the older formations is probably more ıan 1,000 feet, but it can only be accurately determined by drillıg or shaft-sinking. The pre-Tertiary formations on the downırown block, for example, at the townsite of Candelaria, are ɔmpletely covered by alluvium, by Pleistocene basalt, and probbly by a thick section of Tertiary tuff beneath the basalt. This nowledge may be of practical importance in future mining.

The Reservoir fault, and related faults.—The Reservoir fault es along the south margin of Candelaria Mountain and is the ɔunterpart of the Candelaria fault except that it is mineralized ss obviously, or perhaps not at all. The dip, as measured in 9 laces, ranges from 55° to 76° S. The throw, which accumulated ı at least two periods of movement (pre- and post-Pleistocene ısalt), probably amounts to more than 500 feet.

North of the Lucky Hill mine, the Reservoir fault either ranches repeatedly or cuts off impinging faults which strike ortheast. The Reservoir fault, or a principal branch, crosses andelaria Mountain obliquely, from the west fork of Pickhandle ulch toward the mouth of the Gulch. It is a feature to be reckıed with in mines of that vicinity, as a throw of 600 feet is

indicated by the displacement of the Diablo formation. Another principal branch, or related fault, passes eastward, crossing Pickhandle Gulch just below the forks. This has been called the Alpha fault. It dips 50° to 60° S, and forms the north boundary of a block of white Tertiary rhyolite, and tuff (fig. 11). The other side of the block is defined by an opposing normal fault which has been referred to as the Swastika fault. The rhyolite and tuff therefore compose an elongated wedge which narrows downward. The Alpha fault must cut off the Lucky Hill ore bodies if the veins extend that far, and it is said to cut off the Mount Diablo vein group in lower levels of the abandoned mine workings.

Recency of movement.—The Candelaria fault is probably still active, as the accumulation of talus material has been unable to catch up with the uplift of the horst. A vague scarplet at the junction between mountain front and talus cones suggests that faulting has occurred since the cones reached their present height.

The northeast branches of the Reservoir fault offset the basalt above the forks of Pickhandle Gulch, and produce low scarps as high as 60 feet. These are strikingly fresh (pl. 1). Similar small, little-eroded scarps are seen on the basalt capping east of the Gulch.

Origin of anomalous "Basin and Range" trends.—The small recent displacements are but feeble sequels in a complex structural history, and they have been strongly influenced by earlier events.

Some of the conspicuous structural trends in the district were determined long ago, principally by the post-Triassic, pre-Tertiary folding. The pre-Tertiary folding resulted in the prevalent east-west strike of the Permian sandstone and Candelaria shale (see map, pl. 1). This could not have come about during any of the subsequent fissuring, reverse faulting, post-Tertiary gentle folding, or block faulting. Some of these deformations affected the inclination of the beds, but none of them seriously modified the strike. If cross-folding had occurred, the strike could not have remained so nearly uniform.

The early-established strike of the bedding may have influenced the fissuring that is reflected in the dike pattern, and it probably determined the elongation of the serpentine mass. It guided the pre-mineral reverse faulting, much of which was effected by slippage between the inclined strata.

Adaptation of old faults.—The Candelaria fault and the Reservoir fault, which appear recent at first glance, are old faults that ave lately assumed a new role. Apparently they have been taken ver by recent "Basin and Range" movements. Probably the same ertically acting forces which cause movements of the more revalent north-south horsts and graben took advantage of these eady-made east-west fractures.

Elsewhere in Nevada there have been instances of the revival f old faults within historical times. About 10 miles north of 'andelaria, an old fault with no direct topographic expression, 'ell within the Excelsior Mountains, showed a displacement of few inches at the time of an earthquake in 1934, and the ıovement was almost certainly tectonic rather than superficial Callaghan and Gianella, 1935). In 1915 at the time of the leasant Valley earthquake, new scarps appeared not only along ıe foot of pre-existing scarps bounding the Sonoma (Tobin) ange, but also appeared along a "dead" fault extending into the tillwater Range. A dip-slip displacement occurred, amounting) 3 feet in some places.

ORE DEPOSITS

The ore deposits of the Candelaria district have not been ıinutely studied and completely mapped in detail, but sufficient ork has been done to show the geologic setting of the deposits ıd to indicate some valuable guides for exploration. Most of ıe deposits are in northward dipping veins near a single strati-raphic horizon and most of them are enveloped in intensely tered rock.

ROCK ALTERATION

Some of the rocks in the Candelaria district have been serici-zed, argillized, carbonatized, and silicified. These types of altera-on are here attributed to hydrothermal action presaging or :companying ore deposition. This view is supported by the ıatial relations of ore deposits and altered rocks (pl. 1). The tered rocks have been examined in the field more than in the boratory, and microscopic work to date has not been thorough. ıe following descriptions should be evaluated accordingly.

Sericitized and argillized rocks.—Sericitization has clouded the ldspars of many basic dikes and nearly all intermediate and idic dikes. The inner parts of zoned plagioclase laths have been most completedly replaced, and in some rocks all of the feldspar ıs been replaced. Generally minute specks of pyrite are dis-minated in such rocks. The felsite dikes seem to be particularly nsitive indicators of hydrothermal action. If an unaltered dike

was found, it probably could be considered post-mineral in age, or outside the general area of mineralization.

Masses of soft white material in parts of the Mount Diablo mine are thought to be hydrothermally argillized rock, although no laboratory study has been made. The clay-like material occurs near some of the veins, but is not a constant associate.

Carbonatized rocks, and their association with ore deposits.—Carbonatization has produced the most striking transformations and is responsible for the majority of the altered areas shown in plate 1. Nearly all pre-Tertiary rocks except the Palmetto formation have been susceptible, and those which are largely carbonatized show no vestige of original characters. Candelaria shale, rocks of the Pickhandle Gulch complex, and serpentine have been particularly affected. Weathered outcrops of carbonatized rocks are orange-brown, rough-surfaced, devoid of systematic structures, and transected by irregular joints and veinlets. Below the zone of oxidation the carbonate rock is largely gray-white, except for some of the veinlets. It is dense-textured, tough, and contains enough silica to impart a deceptive apparent hardness. The carbonate is predominately microcrystalline dolomite, which occurs in aggregates and in tiny disseminated euhedral crystals. It is generally accompanied by a small amount of chalcedonic quartz. Dolomite and quartz also occur as coarser grained veinlets cutting the earlier, microcrystalline material. Specks of pyrite, or limonite pseudomorphs, are commonly sprinkled through the rock, especially along the veinlets.

The carbonate of the altered rocks varies as to iron and manganese content. Most of the dolomite is ferruginous and, during weathering, develops yellowish brown stains. Iron also appears in the form of siderite, but this is probably not abundant. Some of the dolomite is manganiferous, as indicated by earthy black manganese oxide coatings on weathered surfaces. Neotocite locally forms veinlets and also occurs as microscopic pseudomorphs, rhombohedral in shape, after carbonates. Rhodochrosite was seen in vein material from the Petrel Lode tunnel in Pickhandle Gulch, and it may possibly occur as a constituent of some of the dolomitized rocks.

A common carbonatized rock derived from serpentine is pinkish white to tan white when seen in outcrops at a distance of a few feet. Closer observation shows a gray-white background with rusty splotches and veinlets. The pale material is microcrystalline talc and fine, disseminated dolomite. The rusty splotches are weathered microcrystalline aggregates of ferruginous dolomite.

ome of the veinlets consist of dolomite and others are fine quartz. 'he talc betrays the serpentine ancestry of this type of altered ock. In some places serpentine has been completely transformed o a talc-free aggregrate of carbonate which shows few clues as o its history. Some geologists have considered the dolomite to e an original rock from which the serpentine was derived, but astite and chromite in the serpentine cannot be explained by his theory.

Intensely carbonatized rock is spatially associated with miner-lized veins to a notable degree, although not all mineralized eins are enclosed in carbonatized rock. Examples of close asso-iation are seen in Pickhandle Gulch, where the two principal eins below the forks of the gulch are bordered by orange-brown veathering dolomitized rock. The footwall rock of one of the two eins is altered in a zone 50 to 100 feet thick, and where the vein attens near the site of the abandoned camp of Pickhandle, much f the hillside is dolomitized rock. Accompanying mineralization as attracted prospecting and the hillside is conspicuously pock-narked with adits. The veins of the Lucky Hill mine are virtually ncased in a roughly tabular envelope of dolomitized rock about 00 feet thick. The Mount Diablo veins are somewhat similarly ituated, and the eastward termination of the veins, at the ground urface, approximately coincides with the eastern boundary of e carbonatized zone.

Silicified rocks.—Rocks resembling quartzite form prominent utcrops in many of the alteration areas. Quartzose masses are articularly conspicuous near the Lucky Hill mine, where they re associated with dolomite of hydrothermal origin. It is tempt-ng to suppose that the dolomitization of the Candelaria formation nd other rock units displaced quantities of silica as the clastic articles were replaced by carbonate, and that the silica was eposited almost contemporaneously to form the quartzite-like asses. Also, alteration of the underlying Ordovician(?) chert ould have provided an ample supply of silica, but the chert areas ow exposed show relatively little susceptibility to carbonatiza-on.

It is difficult, if not impossible, to megascopically distinguish me of the silicified rocks from metamorphosed sandstone of the ickhandle Gulch complex.

VEINS

Most of this section applies to the silver-bearing veins, except where otherwise noted.

Varieties of Veins.

Several types of veins occur in the Candelaria district:

Quartz veins.—These are generally thin (1 to 12 inches thick) and white, with few or no rusty stains, and are apparently nearly barren. They are marked "q" on plate 1.

Silver-bearing veins, with some quartz or dolomite gangue.—These veins have been most productive. They are mineralized faults, so limonite-encrusted fault surfaces or cemented fault breccia commonly comprise the outcrops. Surface exposures are heavily stained with brown hydrous iron oxides or black man-ganese oxides, which tend to conceal the scanty to moderately abundant quartz. Such veins have produced silver, gold, lead, zinc, and antimony. They (and possibly some barren veins) are marked "q, Fe" or "q, Fe, Mn" on the map (pl. 1), in allusion to minerals which characterize the outcrops. Fine tourmaline occurs in some of the vein walls, but not as abundantly as in the veins next described.

Tourmaline-copper-bearing veins.—These are less clearly defined than the preceding variety. Although the tourmaline-copper-bearing veins developed along faults, the fault features are nearly obliterated. Outcrops are marked by brown hydrous iron oxides, streaky black aggregates of tiny tourmaline prisms, inconspicuous fine quartz, and small amounts of green copper minerals. Veins of this type have been unproductive to date, although they have attracted prospecting. They are marked "q, t, Fe, Cu" on the map (pl. 1).

Barite veins.—These apparently contain little except the min-eral barite. They are marked "Ba" on the map.

Favorable Horizon.

At first glance, the Candelaria mines appear to be scattered unsystematically. However, many of the silver-bearing veins are actually in a single part of the stratigraphic section, which appears and reappears in various parts of the district because of faulting. Probably the relationship was first recognized by J. A. Burgess (1922). The discovery of this fact could not have been easy, as the formations nearest the mineral deposits are not readily identified.

The key to the relationship between veins and stratigraphy is he Diablo formation, consisting of grit, which generally can be ecognized, even where Candelaria shale is baked or silicified to he extent that it is indistinguishable from Palmetto chert.

The horizon most favorable to veins is just above the Diablo rit bed, and comprises the lower part of the Candelaria formaion. This is illustrated, for example, by veins extending interittently about two-thirds the length of Candelaria Mountain, arallel with the strike of the country rock, at a distance of 100 o 300 feet north of the marker bed. These veins include those f the Potosi (fig. 12), Hecla, and, in part, the Climax mines.

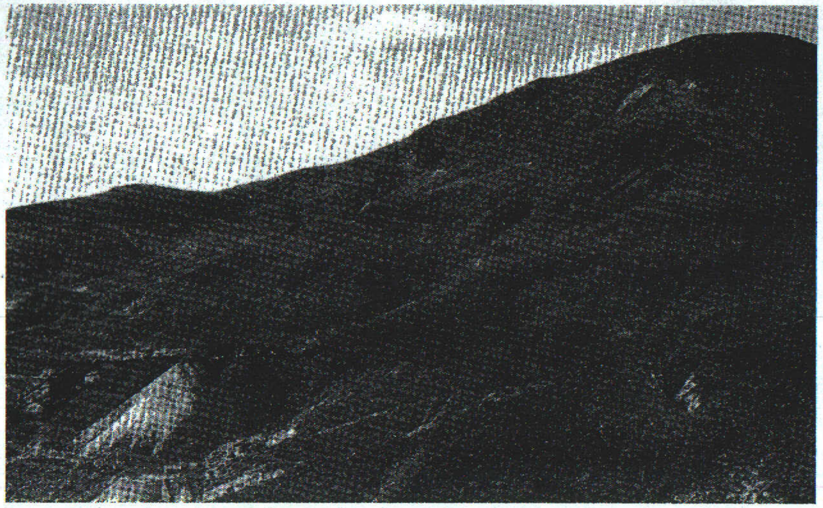

FIGURE 12. Potosi mine, seen from the west. Trace of north-dipping vein is shown by adits and open stopes ascending Candelaria Mountain obliquely at the right.

Vest of the Potosi mine there are 2 or 3 veins side by side, howing that the favorable horizon is by no means confined to a ingle stratum, but comprises a few hundred feet of strata.

The veins of the Northern Belle do not all conform to the avorable horizon, but some of them do, in spite of surface indicaions to the contrary. Obviously those which cross the strike of he country rock at a large angle are not related to any particular tratigraphic member. This fact, plus the concealment of deeper ormations by the Quaternary basalt and the rock complex of ickhandle Gulch, and the deceptive location of the Northern elle shaft at a distance from the vein outcrops, tends to camouage the situation existing at depth. However, Burgess (1922 and 930) found that the vein intersected by the shaft at the 19th

level, about 800 feet below the collar, lies nearly concordantly in Candelaria shale, about 150 feet stratigraphically above the grit of the Diablo formation (figs. 13 and 14). Followed up-dip, this vein passes into the Pickhandle Gulch complex, and it may represent a fault which first began to develop in the usual horizon, and which then extended into adjacent rock units.

The several veins of the Lucky Hill and Mount Diablo mines, although encased in intensely altered rock, are within a few hundred feet of the Diablo grit. The Mount Diablo veins may be even closer than is at first apparent, because the grit is structurally repeated, and remnants of it may be discerned in some of the altered rocks not far from the ore bodies. South of the Mount Diablo mine, 3 or 4 small veins occur in the favorable horizon, which is repeated by faulting.

Two explanations are proposed for the fact that ore deposits favor the lower part of the Candelaria formation: (1) The nearby Diablo grit bed is physically competent and has acted as a substantial structural member during the post-Triassic deformations. Therefore, much of the shearing and faulting was concentrated in the adjacent weak shale, and this provided avenues for mineralizing solutions in the shale. (2) The shale of the lower part of the Candelaria formation is locally calcareous. A few thin limestone beds and lenses occur in this part of the section. The calcareous rocks, where brecciated and pulverized by faulting, were probably more amenable to replacement by vein material than the bulk of the Candelaria formation.

The preceding paragraphs are concerned with the fact that one stratigraphic horizon was favorable to ore deposition. However, this horizon is not the only site of ore formation in the district.

Structural Loci of Mineralization.

The geologic map (pl. 1) plainly shows that the area of greatest structural discontinuity coincides with intense rock alteration and the greatest number of veins. This area encompasses Pickhandle Gulch and the adjacent terrain to the south. It, therefore, includes the Northern Belle, Mount Diablo, and Lucky Hill mines, which were the most productive in the district. To the west and to the east the sedimentary formations are more nearly continuous and are less altered. The surface trace of the Diablo and Candelaria formations describes a broad, faulted arc convex to the north. The area of intense mineralization separates the northwest-trending part of the arc from the northeast-trending part. More significant, this area is marked by the greatest offset in the arc.

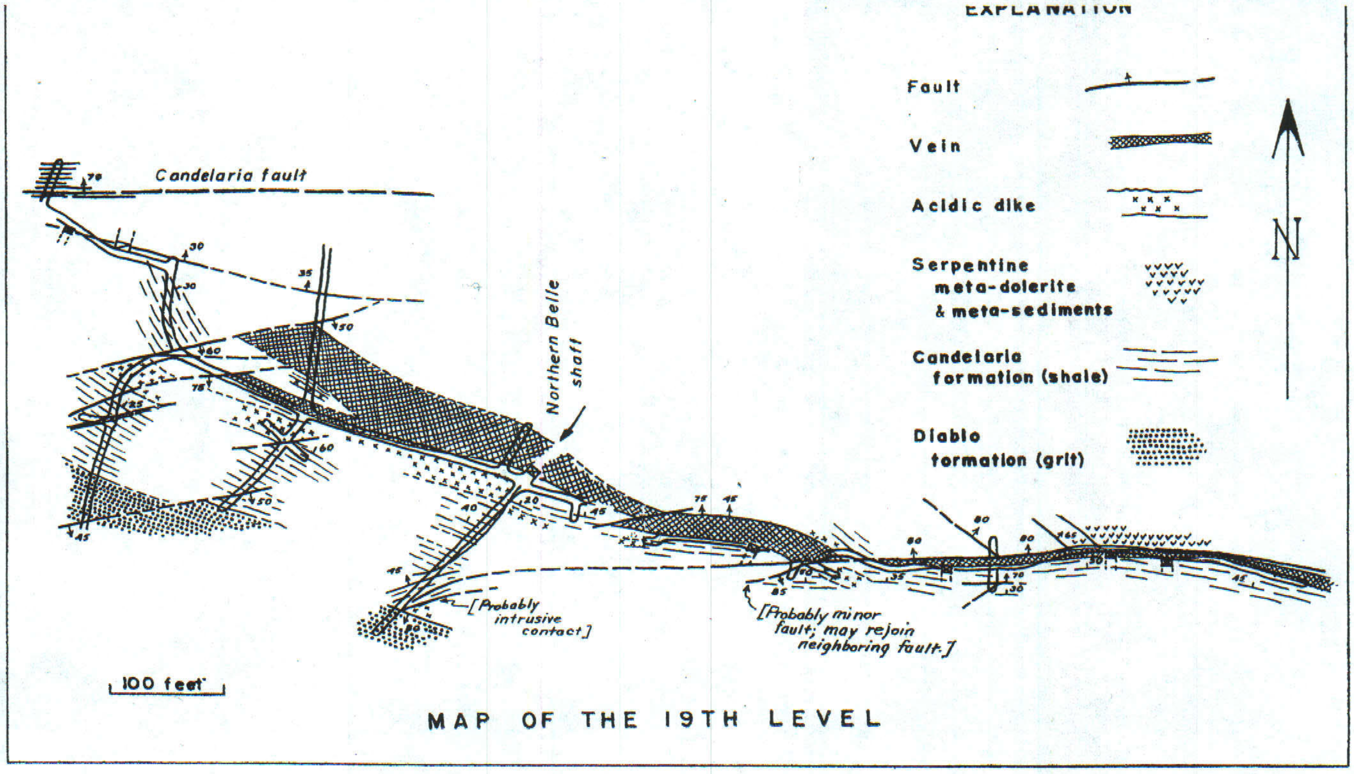

FIGURE 13. Typical underground geology, Northern Belle mine.

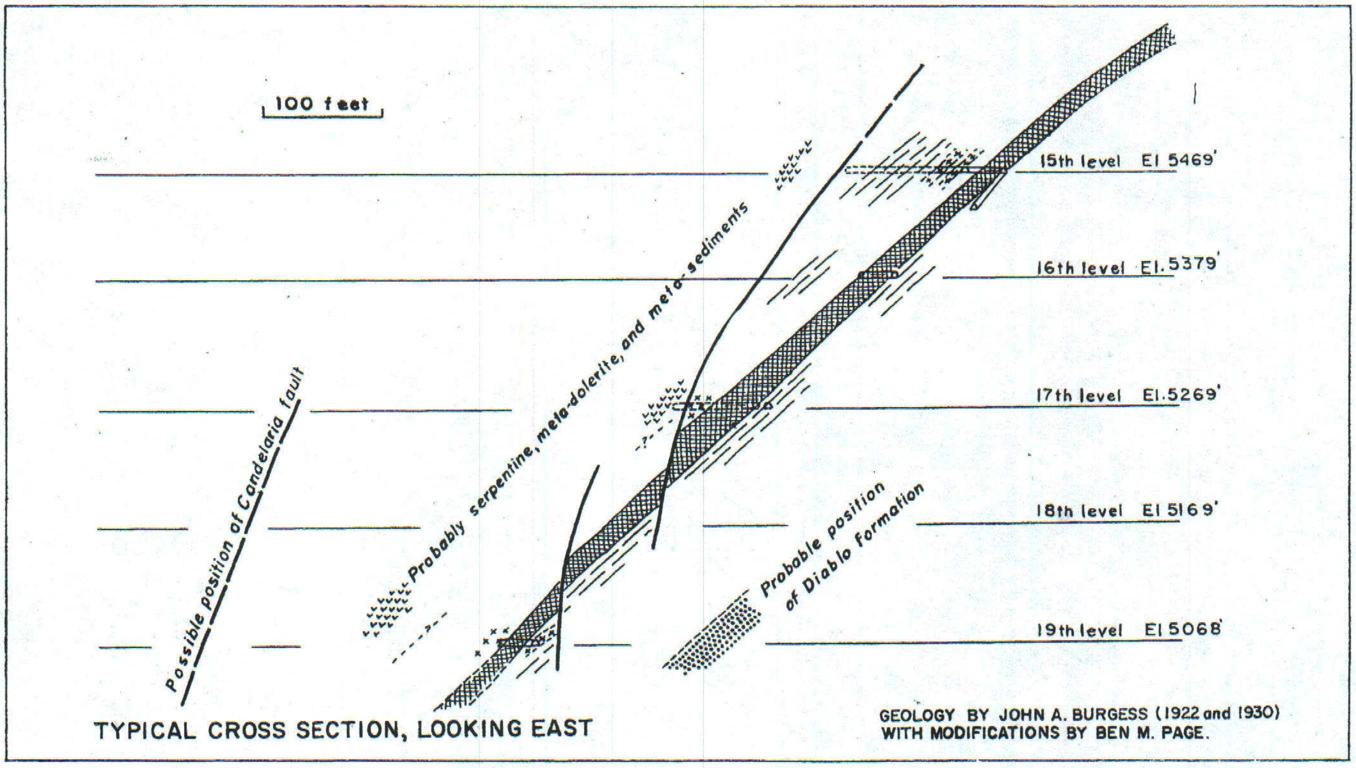

FIGURE 14. Typical underground geology, Northern Belle mine. For legend see figure 13.

he offset has resulted from a long history of recurrent faulting, ıe earlier phases of which are completely obscured by the Pick-andle Gulch complex. The latter probably owes its existence to ıis very same faulting, which paved the way for complicated ıtrusions and rock alteration. Only the more recently reopened ıults are discernible.

The metalliferous veins of the Candelaria district are miner-.ized faults. The parent structures may be divided into non-edding faults, like many of those in the Pickhandle area, and edding faults, which are probably more prevalent to the west ıd to the east of the scene of greatest deformation.

eins That Occupy Bedding Faults.

The bedding faults, such as those occupied by silver-bearing eins in the Potosi mine and the deep levels of the Northern elle, all dip north and are essentially concordant with the beds ' the footwall (figs. 13, 14 and 15). In several exposures near ıe Potosi mine the hanging wall strata are locally slightly crum-ed and abraded against the footwall, indicating that the sense ' the slippage was that of a reverse fault. Crumpling of the ınging wall, on a larger scale, may be inferred from the inter-ting distribution of the "upper grit" marker bed (fig, pl. 1). ıe veins in the vicinity do not mimic the configuration of this ːd, but remain nearly parallel with the less disturbed footwall rata.

Some of the veins apparently occupy bedding faults at certain calities, but extend laterally or vertically beyond the stratified cks and enter massive altered rocks without drastic change in rike and dip. This seems to apply to 1 or 2 east-west veins of e Northern Belle. Possibly the attitude of the faults was initially termined by the attitude of the Candelaria formation, and this ientation was more or less maintained as the faults lengthened ıd entered rock masses devoid of bedding.

ins That Occupy Nonbedding Faults.

Some of the faults which have become mineral-bearing veins ere not influenced by bedding in the country rock. The discovery in of the Northern Belle mine strikes nearly north-south across st-west strata of the Candelaria formation. The silver-bearing ins in the upper levels of the Mount Diablo and Lucky Hill nes are essentially restricted to altered rocks in which strati-ation has disappeared. Oddly, in these mines the mineralized ults strike about east-west and dip north at nearly the same gle (50° to 70°) as the bedding faults in other parts of the strict.

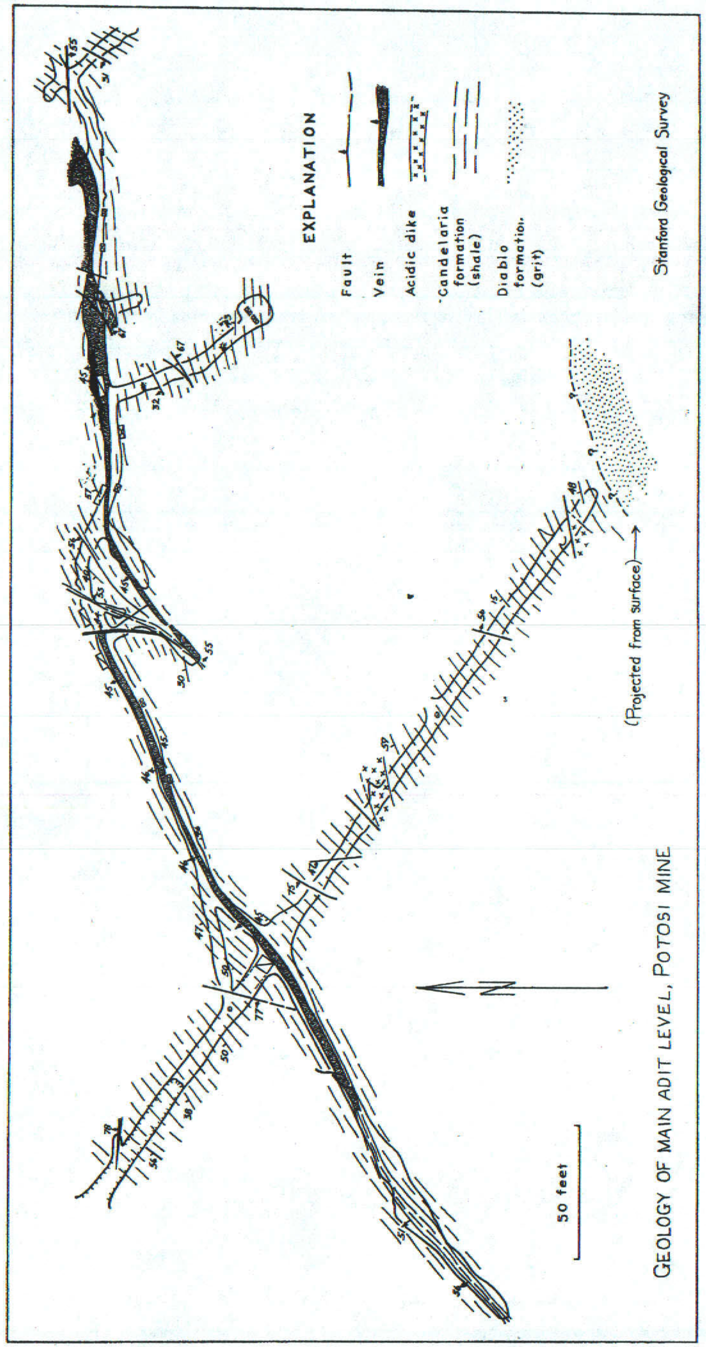

FIGURE 15. Geology of the main adit level, Potosi mine.

epeated Reopening of Fractures and Veins.

Repetitious fracturing alternated with the action of fluids in ıe Candelaria district. The rocks were faulted and locally shat- ›red prior to alteration. The fractures admitted hydrothermal uids, which permeated, and reacted with, the host rocks. In laces this resulted in the development of massive dolomite or ıixed dolomite and fine quartz.

The fractures were healed by the hydrothermal alteration, but ɔt for long. Renewed or continued mechanical disturbance opened ıe altered, and some of the unaltered, rocks. A small amount of ıartz gangue was precipitated in many of the resulting fissures, 'hile quartz and calcite or dolomite were precipitated in others. his newly formed gangue was broken during additional move- ıent, and new solutions left pyrite in the veins. It is clear that ›me of the pyrite was, in turn, brecciated before the deposition : a succession of ore minerals. Later the array of gangue and ılfides was again fractured, as a prelude to the arrival of more ıartz, which occurs scantily as minute veinlets cutting the ırlier vein matter.

Not only did recurrent movement accompany vein formation, ıt it also followed mineralization. The Candelaria fault, which mineralized west of the ruins of Candelaria, is one of the best :amples. It has had a long history of intermittent activity, the test phase of which has been a "Basin and Range" type of ›rmal faulting in the Quaternary period.

SILVER ORES

:neral Distribution and Character.

The ore mined to date has nearly all come from veins. The ost productive veins lie in an area extending from the Mount iablo mine on the east to the Potosi mine on the west. Within is area, silver has accounted for most of the values, but the es contain some gold and base metals as well.

Judged from old stopes, a few of the veins were largely ore, ch as the discovery vein of the Holmes-Northern Belle property. .sewhere, ore occurred in more restricted shoots. Most of the ined ore bodies were on the order of 2 to 10 feet in thickness, ıt some were 20 feet or more in the widest places. Ore bodies moderate thickness apparently extended along the strike 50 100 feet or more, and down the dip several hundreds of feet.

The oxidized ores were the object of early mining. When these :re exhausted in any one mine, operations ceased. For this ıson the major veins were never "bottomed," although some were

followed downward to faults which cut them off before the sulfide zone was reached. The oxidized zone extends from the ground surface to varying depths of several hundred feet. In the Northern Belle mine, oxidation affected most of the ore west of the shaft down to the 17th level, which is 600 to 700 feet below the surface. East of the shaft, weathering is pronounced down to the 12th or 13th levels, 200 to 350 feet deep, but some sulfide ore occurs at the 13th level, and apparently it predominates in successively deeper levels on that side of the shaft. In the Mount Diablo mine the ore is oxidized to the 700-foot level. In the Potosi mine there are local small pods of sulfides within 200 feet of the ground surface, although the major part of the ore is thoroughly oxidized to a greater depth.

The only place in the district where continuous sulfide vein material has been partially developed is the Northern Belle mine, particularly on the 17th and 19th levels. Reportedly some of this vein material is ore. A small tonnage was mined by a lessee in 1926. Some of the sulfides obtained from development work may be seen on the dump at the Belle shaft. The newer, gray parts of the dump contrast markedly with the rusty brown waste from older operations in the oxidized zone.

The workings in sulfide ore were not examined by the writer, as the deep levels of the mines were hardly accessible during the geologic mapping. It is said no water is present. As concluded by Knopf (1922, p. 14), probably the zone of saturation has receded faster than weathering has advanced, perhaps because of a relatively rapid change in climate. Because of this lack of stability in the water level, Knopf predicted that no important zone of sulfide enrichment would be found.

Gangue.

The gangue minerals are not as prominent as in the the silver and gold-bearing quartz veins of many other western districts. Few continuous sheets of vein quartz are found in the Candelaria district. This may explain the inconspicuous aspect of some of the veins. Thin discontinuous streaks of gangue do occur, and they make up a large percent of the ore, but in the oxidized zone they are largely concealed by limonite.

Altered host rock, quartz, and dolomite are the most prevalent gangue materials in the ore specimens studied. One specimen contains a little rhodochrosite. In some specimens, early milky quartz gangue was brecciated, the pieces were rotated, and the breccia was cemented by dolomite prior to further fracturing and ıe introduction of sulfides. In other specimens, quartz and dolo-ıite gangue appear to be intergrown. Some ores show clear ıte quartz in minute veinlets cutting early gangue and sulfides. ›bviously, quartz and carbonates have been deposited in several :ages separated by other events.

rimary Ore Minerals.

Only a few sulfide ore specimens have been studied in detail. ome of the samples came from mine dumps. Others were btained underground by the operators of the Northern Belle and 'otosi mines. A small number of polished surfaces were examined ıicroscopically, and various tests were made, but no intensive ıboratory investigation has been attempted.

Primary ore from the Northern Belle is rudely banded; the ılfide-rich parts more or less alternating with layers of gray-to-lack host rock or with white gangue minerals. The most abundant ıetallic mineral is pyrite (FeS_2), which is chiefly euhedral but ne-grained, occurring both in solid streak-like aggregates and ı disseminated specks. Arsenopyrite (FeAsS) forms rare uhedra in the pyrite and quartz areas of some ore specimens. phalerite, (Zn,Fe) S, is next to pyrite in abundance. It is dark rown and occurs in nearly solid aggregates or bands up to one-ɔurth or one-half inch in width, in some specimens symmetri-ally flanked by pyrite. It apparently does not form masses of ırge size. Chalcopyrite ($CuFeS_2$) occurs in exceedingly minute pecks in sphalerite, showing an "unmixing" relationship; but it ; quantatively negligible in the samples examined by the writer. ·alena (PbS) was only found in a few specimens as microscopic lebs.

As yet there is no adequate mineralogical explanation for ıe high content of silver in the Northern Belle ore. Galena is :arce, and no native silver, or silver compounds have been iden-.fied. A scanty mineral resembling galena, and containing lead, ives negative etch tests to all the routine reagents except pos-ibly KCN, which seems to darken it slightly. It was not found ı most of the ore specimens examined. A lead sulfantimonite (?) ı extremely fine striated needles, about 0.1 mm in length, occurs ı microscopic swarms in some of the quartz of nearly all the amples. Suggestive of stibnite or jamesonite, the needles do not how the requisite properties of either. Locally the prisms are ırge enough and sufficiently coalesced to permit very small scale esting. Etch tests with HNO_3 1:1 are positive, but HCl, KCN, eCl_3, KOH, and $HgCl_2$ give negative results. Microchemical ests show the presence of lead and antimony. Two X-ray powder

photographs were kindly made by Donald E. Lee, but the results were inconclusive. A spectographic analysis of the unidentified needles, embedded in quartz, was generously made by Fred L. Humphrey. This analysis shows abundant lead and antimony, traces of various base metals, and a small amount of silver. Also seen microscopically under high magnification were 2 or 3 other unidentified metallic minerals. Altogether the Northern Belle sulfide ore contains 4 or 5 "unknowns," some of which are probably silver-bearing.

Primary ore in the Potosi mine is not extensively exposed and has been little studied. Unweathered lumps in the oxidized zone, together with the minerals in the oxidized ore itself, are somewhat different from the Northern Belle ore. One specimen of primary ore consists of milk-white quartz containing small prisms and thick veinlets of jamesonite ($Pb_4FeSb_6S_{14}$), which is the most plentiful metallic mineral in the specimen. The jamesonite does not give the conventional reactions to etch tests. It was identified by means of X-ray powder photographs made by Donald E. Lee. Sphalerite is fairly abundant, and some contains microscopic "unmixing" blebs of chalcopyrite. The latter mineral was seen in no other situation, and it is not quantitatively important. Pyrite, some of which appears to be later than the sphalerite, occurs in fine cubes and veinlets. Sparse arsenopyrite euhedra are imbedded in quartz. Some lumps of sulfide ore from the Potosi mine are largely massive galena. This is locally preserved from weathering by enclosing fine-grained quartz gangue, which contains a few limonite pseudomorphs after pyrite. Where less protected, the galena is enveloped in anglesite or cerussite.

The silver in primary ore of the Potosi mine occurs both in galena and in jamesonite, as proved spectrographically by Fred L. Humphrey. Polished surfaces have shown no silver minerals. Therefore, much, or all, of the silver is presumed to lie in the crystal lattices of the two lead minerals.

Secondary Ore Minerals.

Oxidized ore in the Candelaria district contains a good deal of limonite (rust-brown hydrous oxides of iron). This is particularly abundant in the west part of the mineralized area. Some of the near-surface ore shows black manganese oxides, partly derived from hydrothermally altered wall rocks. The Potosi veins, and a few others, locally contain a yellow to greenish-yellow mineral identified by Knopf (1922) as bindheimite ($Pb_2Sb_2O_7.nH_2O$). This is derived from the jamesonite, and is silver-bearing. Weathered ore of the Potosi mine also contains gray anglesite ($PbSO_4$)

nd encrustations of tiny colorless crystals of cerussite ($PbCO_3$). ;mithsonite ($ZnCO_3$) occurs in some of the Northern Belle oxiized ore.

letal Content.

The mineralogy and proportions of the metals varies from east o west. On the east side of the mine area, in the Northern Belle nd Mount Diablo, silver greatly overshadowed gold in quantity nd value; much of the oxidized ore averaged about $65 in silver nd $1 in gold. On the other hand, gold was important in ores roduced on the west side at the Potosi mine, and at present some mall remnants of oxidized ore are said to contain an ounce of old per ton. On the basis of the few samples of sulfide ore tudied, it seems likely zinc is the principal base metal on the ast side of the productive area, while lead is probably much nore plentiful than zinc on the west side of the area. Antimony s present in the primary ore throughout, but appears to be most bundant on the west side.

The oxidized ore mined in early days must have averaged 30 o 90 ounces of silver to the ton, in view of the costs of mining, ransportation, and treatment. Judged from tonnages and values uoted in "Nevada's Metal and Mineral Production" (Couch and 'arpenter, 1943), the ore shipments from Candelaria in the 870's declined from about $90 to $40 per ton within a decade.

Several thousand tons of mixed oxide and sulfide ore shipped y G. A. Peterson from the Potosi mine during 1948–1952 was alued at $35 to $75 per ton. The average metal content per ton vas as follows (G. A. Peterson, personal communication, 1952):

Gold	0.5–0.6 ounce
Silver	8–12 ounces
Lead	8–12 percent
Antimony	4–6 percent
Iron oxide	12–15 percent
Copper	0.5 percent
Zinc	0.5 percent

'ayment was received from the smelting company for four ietals: gold, silver, lead, and antimony.

The sulfide vein material now partially developed in the lower evels of the Northern Belle mine contains from 1 to 106 ounces f silver per ton, according to assay maps of the Argentum lining Co. Local ore shoots of modest dimensions reportedly arry 10 to 30 ounces of silver per ton, and a little lead and zinc. 'robably there is a much lower content of gold and lead, and

possibly a higher content of zinc, than in the above-described ore from the Potosi mine.

MISCELLANEOUS MINERAL DEPOSITS

Copper Showings.

Green and blue copper carbonates and sulfates have attracted attention to some of the tourmaline-bearing veins, such as that of the Climax mine area. Lack of extensive workings in these well-exposed deposits would seem to indicate that the copper content is low, at least near the ground surface. Copper showings are conspicuous in other types of very small veins a quarter of a mile east of the Climax adit and in a small dissemination 600 feet northwest of the same adit. Copper minerals are evident 600 feet southeast of the Mount Diablo shaft and in widely scattered prospects to the east. Some showings are even found near the south edge of the mapped area in chert of the Palmetto formation, which is poorly mineralized elsewhere in the district. Nowhere is copper mineralization both intensive and extensive, judging from surface exposures.

Nickel and Chromium Showings.

According to Lincoln (1923, p. 141), 10 tons of high grade nickel ore was mined in 1882 somewhere near Columbus. The writer does not know the locality from which this ore came, but supposes that it was the serpentine area. Nickel is not mentioned in subsequent reports. A spectographic analysis kindly made by Fred L. Humphrey showed a minor amount of nickel and chromium, as well as a trace of tin in a single sample from one of the tourmaline-bearing veins of Candelaria Mountain.

Chromite ($FeCr_2O_4$) has been reported in specks and streaks in the main serpentine mass. Inasmuch as serpentine is the customary host rock for chromite, and because the serpentine body at Candelaria is the largest known in Nevada, a brief examination was made by the Nevada Bureau of Mines (Prince, R. W., 1946). This preliminary reconnaissance failed to disclose any deposit of economic value. The main showings were two small lenses of chromite on the C & M No. 1 claim, both showings being near the south margin of the serpentine. One of the lenses was about 6 feet long, 10 inches thick, and extended down the dip about 6 feet.

Serpentine.

The serpentine, itself, has been quarried on a small scale and used in the treatment of magnesite at Gabbs, Nev. Probably less than 1,000 tons has been shipped for this purpose.

/ermiculite.

Flakes of vermiculite (hydrous silicate of Mg, Fe, and Al))ccur in streaks and disseminations in altered serpentine 600 feet ıorthwest of the Mount Diablo shaft. Outcrops and prospect pits lo not show commercial concentrations, although individual ver-niculite flakes are fairly large, being one-eighth to 1 inch in liameter. The enclosing rock is a white soft aggregate of talc and remolite extending over an area of a few thousand square feet.

'alc.

Talc, $Mg_3Si_4O_{10}(OH)_2$, is found along fractures in the serpen-ine mass. In most cases it is highly sheared, admixed with other ıinerals, and restricted to thin, curving, lenticular seams a few ıches thick. One prospect pit exposes talcose material 4 to 5 feet /ide, in the main mass of serpentine, near its south border Prince R. W., 1946). This is on a claim known as C & M No. 1. .nother prospect near the north side of the same claim, and near ıe north border of the serpentine, has exposed talcose material) a depth of 12 feet (Prince, R. W., 1946). No minable talc has een found. It should be mentioned that most of the talc contains ıore iron than is permissible for uses such as ceramics, elec-'ical equipment, and cosmetics.

ırite.

Veins of barite ($BaSO_4$), marked "Ba" on the map (pl. 1) are ıirly long, but narrow. Some barite was mined on a small scale . the 1930's, and about 200 to 2,000 tons were produced in the)40's, probably for use in oil-well drilling mud. There has been) recent activity. The surface cuts from which barite was moved show vein widths of 1 to 3 feet, but most of the exposed ·ins are narrower than 1 foot. Dips appear to be nearly vertical. ›me of the barite is white, but some is stained reddish brown · iron oxide. The texture varies from medium to coarse, some the material consisting of closely packed lamellar crystals up 1.5 inches long. The barite veins have sharp contacts with the ıll rocks, which are invariably Candelaria shale or felsite dikes. ructurally, the veins probably represent filled tension fractures.

rquoise and Variscite.

Turquoise, $CuAl_6(OH)_8(PO_4)_4.5H_2O$, and variscite l,Fe) $PO_4.2H_2O$, both occur in the Candelaria district. Variscite !ight green, but in other respects resembles turquoise. The two ıerals occur in exactly the same way, forming discontinuous nlets. The veinlets range from less than .01 inch to about 0.5 h in thickness, and are somewhat irregular, varying greatly in

thickness and subdividing into branches within a distance of a few feet. Rarely are the zones of veinlets traceable for more than 50 or 100 feet, yet several thousands of pounds of commercial material have been laboriously picked out by hand from shallow pits and trenches.

One of the sites of small scale turquoise and variscite mining is about 100 feet west of the glory hole at the discovery vein of the Holmes-Northern Belle area on the summit of Candelaria Mountain. Here, and in several places in the southeast part of the mapped area, the veinlets are found cutting across shale beds in the lower part of the Candelaria formation. This part of the formation locally contains ellipsoidal phosphatic nodules up to three-fourths of an inch long. Therefore, the sediments probably provided the phosphate of the turquoise and variscite. This concept is weakened by 1 or 2 occurrences of variscite in chert and shale of the Palmetto formation, but these sediments also may have been phosphatic.

CONCLUSIONS AND RECOMMENDATIONS

POSSIBILITIES FOR FUTURE MINING

During its active period the Candelaria district produced silver from oxidized ore. This phase of activity has probably been completed, although a few small segments of veins in the oxidized zone were missed by the early operators, especially in structurally complicated localities.

The lower parts of the veins have been little explored, as the sulfide vein matter was not workable at the time of the early operations. It remains to be seen whether this primary vein material can be profitably mined.

The following considerations are favorable:

1. Whereas the early operations chiefly recovered silver and gold, it would now be technically possible (but not inevitably profitable) to extract lead, zinc, and antimony as well as the precious metals.
2. Exploration methods, mining methods, and equipment have improved.

On the other hand, the following considerations are unfavorable:

1. The oxidized ore was enriched by weathering, and apparently the grade declined as the mines grew deeper, so the sulfide ore will probably be leaner with respect to gold and silver.

. Judging from available samples, the base-metal sulfides do not occur in great quantities.

. Many of the veins are too narrow to be mined primarily for base metals, assuming the ore is only of moderate grade.

. There is little likelihood a zone of enrichment exists at the water table. Silver and gold have obviously remained in the oxidized zone, lead and zinc are generally not concentrated at the water table, and copper is not plentiful in the primary ore.

. The ore bodies may be too small to allow much mechanization of mining.

. Future mining will, in general, be deeper and involve more hoisting than before.

The water system of Candelaria has disintegrated.

The electric power system has been dismantled.

The railroad has been removed.

The question of present-day costs as compared with those ıring Candelaria's hey-day cannot be answered without more ɛtailed knowledge of the ore and the size of ore bodies. In small ɔerations, higher prices of metals might be more than offset by ıe high cost of labor and materials.

Interested parties will have to weigh the factors, pro and con, ıd favorable areas, explore and sample, then reduce the qualita-ve considerations to quantitative data.

FUTURE EXPLORATION

The foregoing discussion has assumed some ore remains. This ısumption is probably valid, but some of the remaining ore may ɔt be easily accessible.

Some veins formerly worked may simply be followed down dip, ıt others are cut off by faults at depth. This is probably true of me of the veins of the Mount Diablo mine and the Lucky Hill ine, both of which are doubtless affected by the faults that tend east-west past the Swastika shaft. Some of the veins of e Northern Belle mine will probably be cut at depth by the ındelaria fault. One method of ore search in the district is to termine the character and magnitude of fault displacements, the hope of finding missing segments of faulted veins. Explora-ɔn north of the Candelaria fault or east of Northern Belle will rtainly have to take into account a probable great thickness of rren Tertiary volcanic rocks intervening between the Quater-ry basalt and the mineralized formations.

Exploration for new ore bodies should be guided toward three geological features described in preceding pages: Favorable stratigraphic horizon, favorable structure, intensely altered rocks. Probably at least two of these should be found in a given area before a great expenditure is made.

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INDEX

PUBLICATIONS OF THE NEVADA BUREAU OF MINES AND ASSOCIATED ORGANIZATIONS

Publications listed with a price can be purchased from the Director, Nevada Bureau of Mines, University of Nevada, Reno, Nevada. With each order add $0.15 for each publication to cover postage and handling costs.

It will be noted that several different publication series have been started, owing to changes in administration and/or cooperating agencies. In order to facilitate cataloging and bibliographic listing, the numbers at the left in brackets [ ] have been assigned to all bulletins concerning geology, mining, or related material published prior to the establishment and separate numbering of the "Geology and Mining Series."

*An asterisk (*) indicates that the publication is out of print.

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[1]. Preliminary report on the building stones of Nevada, including a brief chapter on road metal, by J. A. Reid. 61 p. incl. illus. Geology and Mining Dept. Bull., vol. 1, no. 1. Univ. Nev. June 1904. 10¢.

BULLETIN OF NEVADA STATE BUREAU OF MINES AND MACKAY SCHOOL OF MINES'

*[2]. Mineral resources of southern Nevada, by J. A. Carpenter. 23 p. Nevada State Bureau Mines and Mackay School Mines Bull., vol. 1, no. 1. Nov. 1929.

UNIVERSITY OF NEVADA BULLETIN

*[3]. The ventilating-system at the Comstock Mines, Nevada, by G. J. Young. 55 p. incl. tables, diagrs. Univ. Nev. Bull., vol. 3, no. 4. Oct. 1909. (Reprinted from Am. Inst. Mining Engineers Bull., no. 35, pp. 955–1009, 1909. Also published in Am. Inst. Mining Engineers Trans., vol. 41, pp. 3–57, 1910.)

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[26]. Geology of the Chief District, Lincoln County, Nevada, by Eugene Callaghan. 29 p. illus., maps (1 fold.) table, diagrs. Univ. Nev. Bull., vol. 30, no. 2. March 1936. 20¢.

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8. Geology and Mining Ser. A contribution to the published information on the geology and ore deposits of Goldfield, Nevada, by Fred Searls, Jr. 24 p. fold. map (in pocket). Univ. Nev. Bull., vol. 42, no. 5. Oct. 1948. 50¢.

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52. Nevada oil and gas drilling data, 1906–1953, by Joseph Lintz, Jr. 80 p. illus., map (2 fold.), tables. 1957. $1.

53. Iron ore deposits of Nevada.
Issued only in separate chapters, as indicated below. Each chapter contains its own index.
(A) Geology and iron ore deposits of the Buena Vista Hills, Churchill and Pershing Counties, Nevada, by R. G. Reeves and V. E. Kral. 32 p. illus., 8 fold. maps (in pocket) tables. 1955. $1.
(B) Iron ore deposits of west-central Nevada, by Robert G. Reeves, Fred R. Shawe, and Victor E. Kral. 46 p. illus. 6 fold. maps (in pocket) tables. 1958. $1.50.

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55. Silica resources of Clark County, Nevada, by T. D. Murphy. 28 p. maps (1 fold.) tables. 1954. 50¢.

56. Geology of the Candelaria mining district. Mineral County, Nevada, by Ben M. Page, 67 p. illus., 1 fold. map (in pocket), tables, 1959. $2.00.

PUBLICATIONS OF THE U. S. BUREAU OF MINES
(In Cooperation with the University of Nevada)

*Technical Paper 423. Cyanide extraction of gold and silver associated with arsenic and antimony in ores, with especial reference to those in Nevada and South Dakota, by E. S. Leaver and J. A. Woolf. iv, 52 p. plates, diagr., tables. 1928.

*Technical Paper 457. Centrifugal concentration: Its theory, mechanical development and experimental results, by H. A. Doerner. iv., 39 p. plates, diagrs., tables. 1929.

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*Technical Paper 609 (Revision of Tech. Paper 438). Bentonite: Its properties, mining, preparation, and utilization, by C. W. Davis and H. C. Vacher. Revised by J. E. Conley. 83 p. diagr., tables. 1940.

PUBLICATIONS OF THE U. S. GEOLOGICAL SURVEY
(In Cooperation with the Nevada Bureau of Mines)

Map MF 138. Geologic Map of Clark County, Nevada, by Ben Bowyer, E. H. Pampeyan, and C. R. Longwell. 1958. 50¢. (Order *only* from U. S. Geological Survey, Federal Center, Denver, Colorado.)

GEOLOGIC MAP OF THE CANDELARIA MINING DISTRICT, NEVADA

Mapping done by students under direction of D. M. Lemmon, B. M. Page, J. D. Barksdale, F. R. Kelley, C. V. Campbell, E. F. Cook, E. E. Roberts, B. W. Ryan, H. P. Schaub, and C. Webster.

Cartography by Beverly A. Malarkey

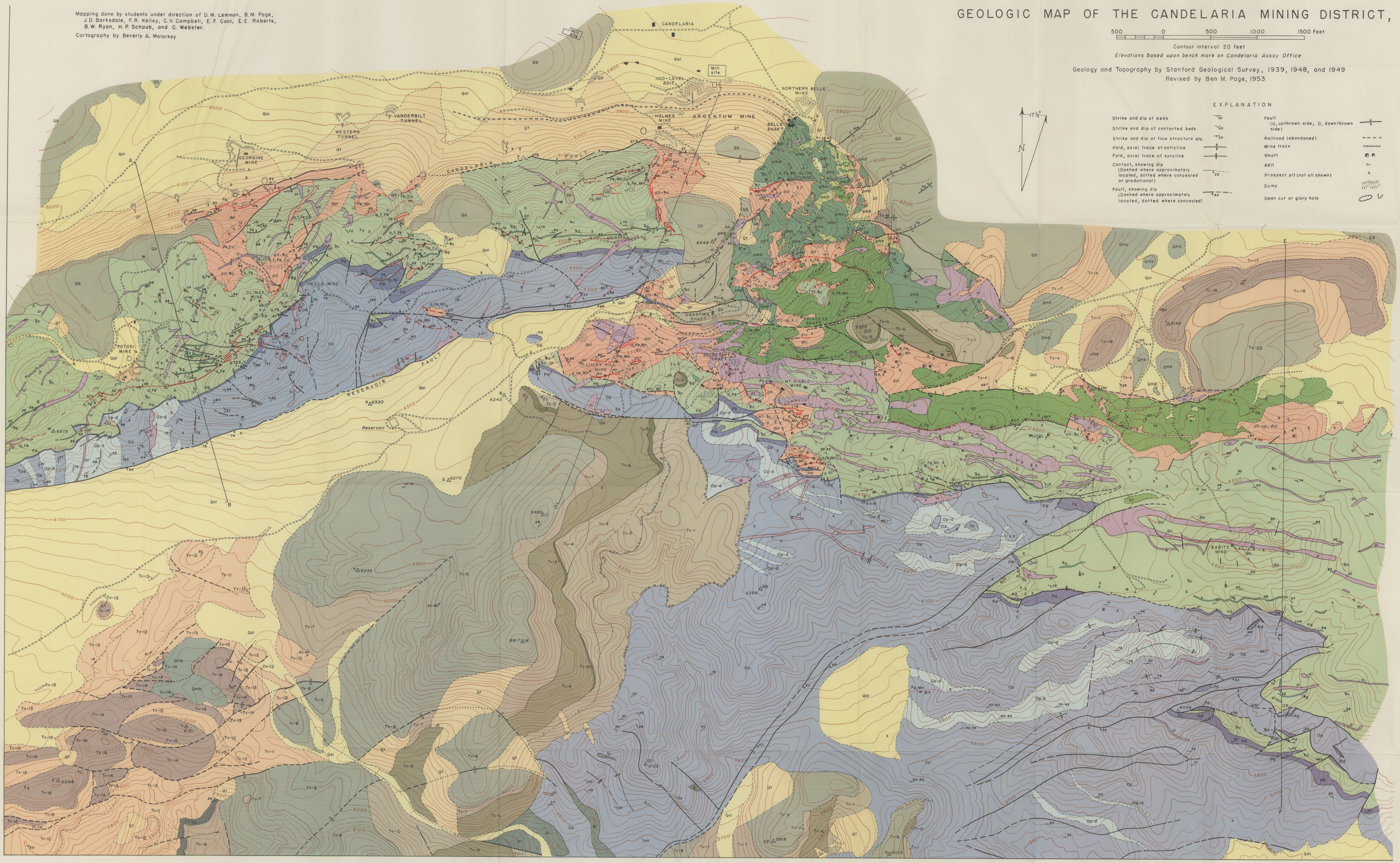
500 0 500 1000 1500 Feet

Contour interval 20 feet

Elevations based upon bench mark on Candelaria Assay Office

Geology and Topography by Stanford Geological Survey, 1939, 1948, and 1949

Revised by Ben M. Page, 1953



EXPLANATION

- Strike and dip of beds
- Strike and dip of contorted beds
- Strike and dip of flow structure etc.
- Fold, axial trace of anticline
- Fold, axial trace of syncline
- Contact, showing dip (Dashed where approximately located, dotted where concealed or gradational)
- Fault, showing dip (Dashed where approximately located, dotted where concealed)
- Fault (U, upthrown side; D, downthrown side)
- Railroad (abondoned)
- Mine track
- Shaft
- Adit
- Prospect pit (not all shown)
- Dump
- Open cut or glory hole

ROCKS AND MINERALIZATION IN APPROXIMATE SEQUENCE

SURFICIAL DEPOSITS

QUATERNARY
- Talus material — Qt
- Alluvium — Qal

VOLCANIC AND RELATED ROCKS

- Olivine basalt — Qb
- Andesitic mudflow breccia — Qmb
- Basalt; with underlying gravel, boulders, and breccia — Tv-20

TERTIARY
- Dacitic rocks
  - Dacitic tuffs and welded tuffs (Tv-11, Tv-12, Tv-13, Tv-15, Tv-17, Tv-19, and several tuffs labelled Tv-x)
  - Dacite flows (Tv-14, Tv-16, Tv-18)
  - Tv-x, Tv-19, Tv-18, Tv-17, Tv-16, Tv-15, Tv-14, Tv-13, Tv-12, Tv-11
- Olivine basalt — Tv-10
- Rhyolitic tuff — Tv-9
- Hypersthene basalt — Tv-8
- Dacitic and rhyolitic rocks
  - Tuff — Tv-7
  - Rhyolite flow — Tv-6
  - "Pseudovitrophyre" welded tuff — Tv-5
  - Tuffs (Tv-1, Tv-2, Tv-3, Tv-4) Gravels beneath Tv-1 and Tv-2, shown by small circles — Tv-4, Tv-3, Tv-2, Tv-1

VEINS AND MINERALIZED ZONES

UPPER JURASSIC (?)
- Quartz vein, apparently barren — q
- Silver-bearing veins, or veins which might contain silver. (Gold, lead, zinc, and antimony may also be present) Outcrop marked by quartz (q), iron oxides (Fe), and locally manganese oxides (Mn) — q, Fe; 70; 61; q, Fe, Mn
- Copper-bearing zones
  - Tourmaline-copper-bearing vein (q, t, Fe, Cu) — q, t, Fe, Cu; 59
  - Copper-bearing dissemination and vein (Fe, Cu) — Fe, Cu
- Barite vein — Ba; 72

ALTERED ROCKS

- Rocks completely replaced by dolomite (dol), silica (stippled), or unspecified minerals (alt) — dol; alt
- Rocks which retain some original features. Altered Candelaria shale (alt-Ꞧc), and serpentine (alt-sp) — alt-Ꞧc; alt-sp

PRE-MINERALIZATION ROCKS

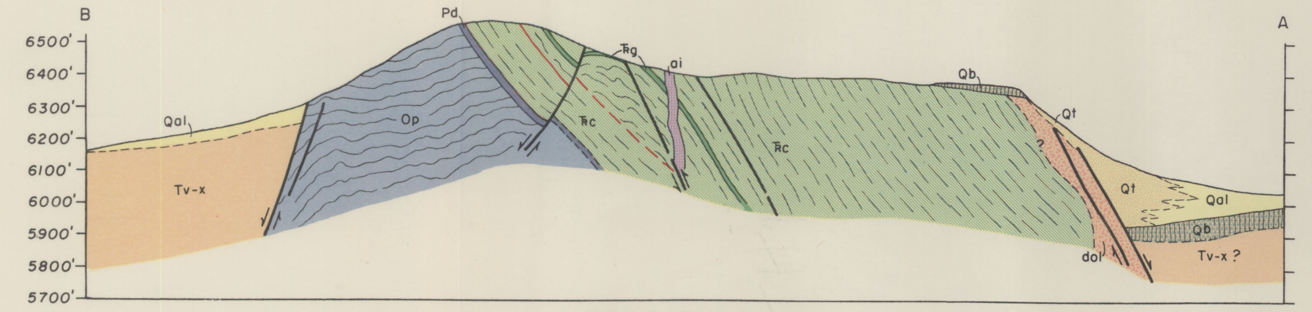
JURASSIC(?)
- Acidic and intermediate dike rocks; felsite, quartz monzonite porphyry, etc. — ai
- Basic dike rocks, diabase, dolerite, etc. — bi
- Serpentine (sp) with meta-sedimentary inclusions (ms) — sp; ms

- Rock complex of Pickhandle Gulch
  - Meta-dolerite (pmd) and obscure meta-sediments (pms) intimately intermingled — pmd; pms

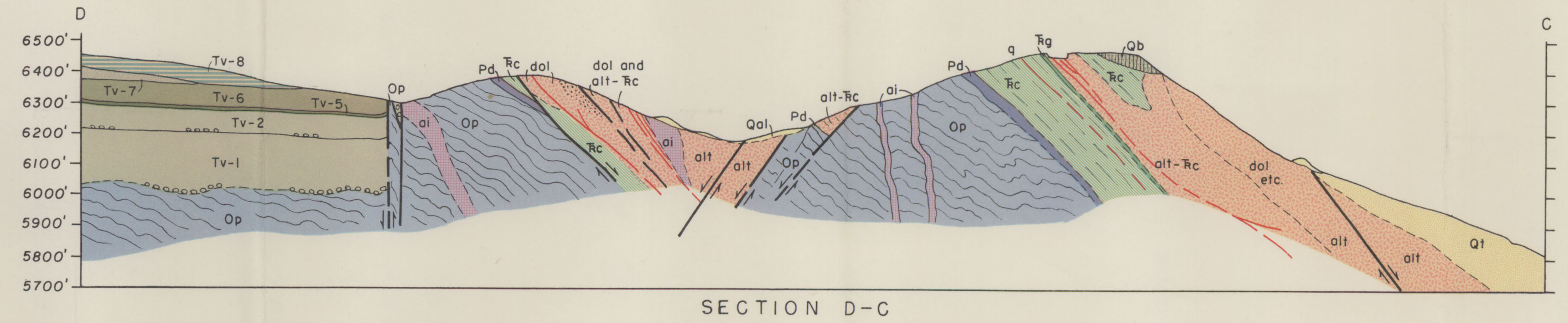
LOWER TRIASSIC
- Candelaria Formation
  - Chiefly shale; locally argillite — Ꞧc
  - Thin grit bed (Ꞧg) in lower part — Ꞧg
  - A few thin limestone beds, not shown, near base

PERMIAN
- Diablo formation
  - Grit or sandstone consisting largely of chert grains — Pd

ORDOVICIAN
- Palmetto formation
  - Chert and shale or phyllite (Op) — Op
  - Thin-bedded dolomite, and shale or phyllite (Opd), incompletely mapped — Opd



SECTION B-A



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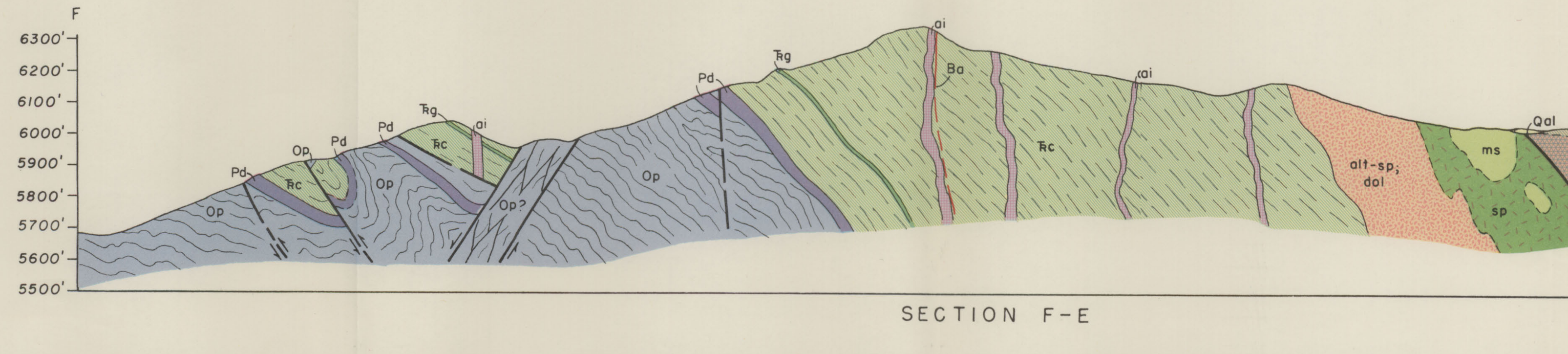

SECTION F-E

WILLIAMS & HEINTZ LITHOGRAPH CORPORATION, WASHINGTON, D. C.