THE MOGOLLON DISTRICT, NEW MEXICO.[1]

By Henry G. Ferguson.

INTRODUCTION.

The Mogollon (mo-go-yohn′) or Cooney district is in the southwestern part of Socorro County, N. Mex., about 14 miles from the Arizona line. (See fig. 29.) Silver City, the nearest available railroad point, is about 85 miles to the southeast. The district lies near the western border of the Mogollon Range, which here presents a

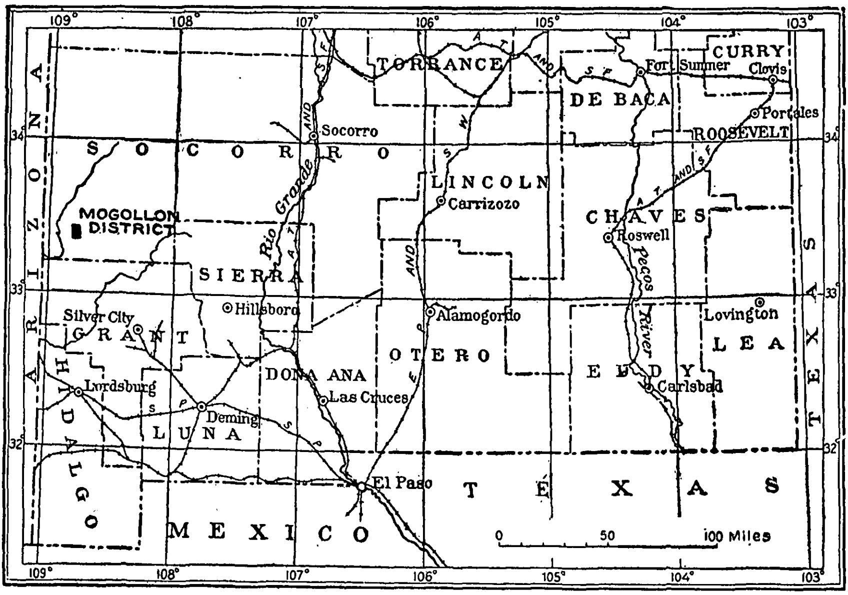

Figure 29.—Map of southwestern New Mexico showing the location of the Mogollon district.

steep front facing the valley of San Francisco River, to the west. The crest of the range, marked by a line of high peaks, is a few miles to the east. To the south the change from mountain to valley topography is less abrupt, and the steep rock cliffs facing the valley are not so prominent a feature of the landscape as they are near the Mogollon district.

[1] This paper was transmitted for publication prior to the appearance of an excellent article on the ore deposits of the Mogollon district by David B. Scott in Mining and Metallurgy, No. 158, section 33, February, 1920. The writer has, however, added a few notes drawn from Mr. Scott's paper.

The plains to the west and south of the mountains show the characteristic vegetation of semiarid regions. In the Mogollon district, however, there is considerable rainfall and heavy showers are frequent, particularly during the summer. A rather scrubby vegetation, including several varieties of small oaks, mountain mahogany, and small juniper and piñon, characterizes the district itself. The higher hills east of the Mogollon district are heavily wooded and furnish an abundant supply of mine timber.

The district was visited by L. C. Graton in 1905, and his report was published in 1910.[2] In 1915 a survey for a detailed topographic map of the district on a scale of 1:24,000 was made by R. W. Berry. The writer spent three months during the autumn of 1916 in a study of the geology. The war prevented the completion of even a preliminary report, and the district was therefore revisited in September, 1919, when about two weeks was spent in the field. The following report is presented as preliminary to a more detailed study, which it is hoped to complete in the near future.

The writer desires to thank his friends in the Mogollon district, particularly Messrs. S. J. Kidder, C. A. Botsford, W. Johns, C. E. Wheelock, R. P. Wheelock, and G. C. Baer, for their assistance and helpful suggestions. Detailed reports on the geology of the Last Chance and Maud S. mines, by Wilbur H. Grant, of San Francisco, made available by the courtesy of Mr. S. J. Kidder, and geologic maps of a portion of the district, by Mr. G. C. Baer, were studied with much profit.

HISTORY.

In August, 1875, James Cooney discovered rich silver-copper ores in the canyon of Silver Creek. The first settlement, now abandoned, was made in this valley and bore the name of Cooney. The region was infested by Apaches, and development work was slow. The first shipment was not made until 1879. In 1880 Cooney was killed by Apaches while assisting in the defense of the settlements in the San Francisco Valley. It was not until 1885 that the Indians ceased to be dangerous. The silver sulphide ores of the Mineral Creek region were discovered about this time, and the present village of Mogollon was established. Mining now proceeded actively, and Graton[3] estimates that up to 1905 the total production had been about $5,000,000 in silver, copper, and gold. The following table[4] shows the annual production of the district since 1904:

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[2] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 191–201, 1910.

[3] Graton, L. C., op. cit., p. 192.

[4] U. S. Geol. Survey Mineral Resources, 1917, pt. 1, p. 719, 1918.

Mine production in Mogollon or Cooney district, Socorro County, N. Mex., 1904–1917.

Year.	Ore.	Gold.	Silver.	Copper.	Lead.	Total value.
	Short tons.		*Fine ounces.*	*Pounds.*	*Pounds.*	
1904	11,276	$61,880	79,014	422,308		$162,484
1905	15,534	97,158	240,943	295,175		288,735
1906	16,076	127,907	268,567			307,847
1907	20,698	105,413	418,338	150,000		411,516
1908	19,546	116,418	278,939			264,256
1909	23,945	111,464	249,413	46	49	241,167
1910	50,514	304,210	595,669			625,871
1911	102,219	531,358	1,067,038	1,873	1,862	1,097,206
1912	101,361	524,858	1,093,158	184	386	1,197,197
1913	115,739	619,886	1,306,766	4,418	1,217	1,409,912
1914	136,124	629,102	1,410,327		590	1,409,035
1915	119,710	509,165	1,301,059		2,426	1,168,916
1916	118,257	373,068	1,008,483	858	3,232	1,037,084
1917	111,934	258,620	722,642	414	1,593	854,327
	962,933	4,370,307	10,040,356	875,276	11,355	10,475,553

TOPOGRAPHY.

The Mogollon district is on the western flank of the Mogollon Range, which rises abruptly from the valley of San Francisco River. Between the flat river bed, which at Alma is about 4,900 feet above sea level, and the mountains are flat-topped mesas of partly consolidated gravels, with altitudes ranging from 5,400 feet on Whitewater Mesa to more than 6,000 feet at the top of the mesa north of Copper Creek. Above these flat mesas are the steep, forbidding cliffs of the Mogollon Range. This frontal wall is trenched by deep stream canyons. Mineral Creek and Silver Creek cross the area covered by the accompanying detailed map (Pl. XV) from east to west, and Houston Canyon drains a small tract in the southeastern part. The magnificent canyon of Whitewater Creek is just south of the area, and to the north is Copper Creek, both about parallel with Silver and Mineral creeks. The stream canyons are extremely youthful, and their walls, particularly near the scarp that marks the front of the range, are precipitous. In the western part of Mineral Creek canyon, locally called Cooney Box, the altitude at stream level is 5,450 feet; at the edge of the plateau, 600 feet to the north, it is 6,300 feet. The topography of Silver Creek canyon is similar, but for the most part the cliffs are not so steep. Along Whitewater Creek the canyon walls are as steep as in Cooney Box. Farther up the stream courses the valleys, although still bordered by sharp cliffs, are not of the box-canyon type which characterizes them at their exit from the range.

Above the cliffs the topography changes abruptly and the interstream areas are comparatively flat between altitudes of 6,300 feet in the western part of the area shown on the map, and 7,500 feet in the eastern part. The boundary between this upland bench and the stream canyons is nearly everywhere sharply defined. This plateau is less well developed in the interstream area south of the Mogollon district and better developed in those to the north, particularly between Copper and Deep creeks.

Eastward from the area mapped this bench disappears and the ground rises steeply to the line of peaks which forms the crest of the range. Cooney Creek heads on the south slopes of Bearwallow Mountain, which has an altitude of 9,920 feet. Willow Mountain, with an altitude of 10,800 feet, stands opposite the head of Silver Creek. Other peaks of the range south of Willow Mountain are Whitewater Baldy, 10,892 feet; Center Baldy, 10,532 feet; and Mogollon Peak, 10,778 feet.

West of the crest the aspect of the mountains changes completely. The slopes are smooth and gradual and the streams, all tributary to Gila River, have cut only shallow canyons. A short distance east of the crest the interstream areas are nearly flat and contain numerous small lakes.

GEOLOGY.

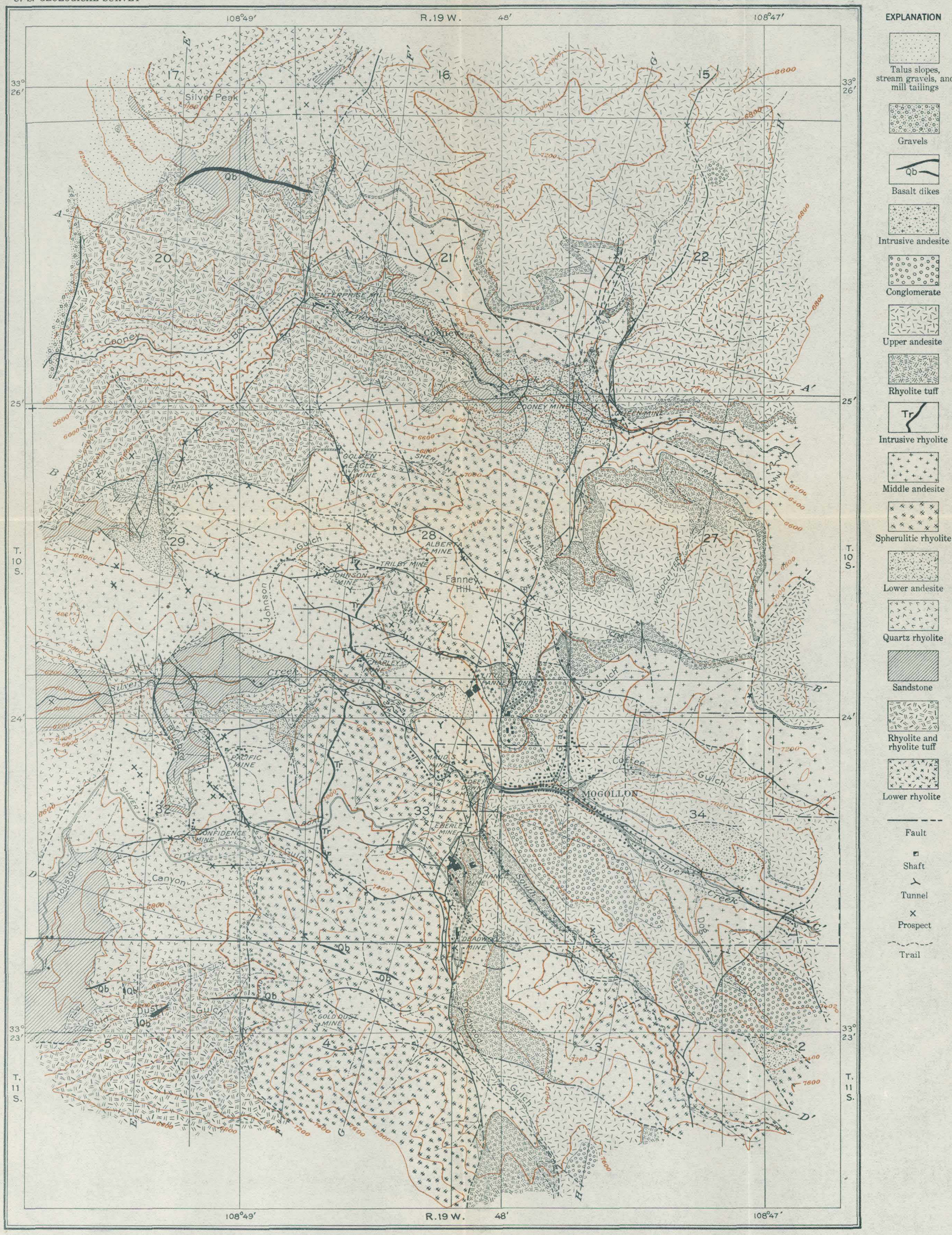
The rocks of the Mogollon district (see Pl. XV) are dominantly lavas, of Tertiary age, separated by sandstones that represent periods of quiet between volcanic outbursts. After extensive faulting mineral-bearing solutions found access to the fault fissures. In Quaternary time the rocks were considerably eroded and a thick covering of gravel was laid down. Then followed renewed faulting, in which the principal fault plane was along the present front of the range, with downthrow on the west. Renewed erosion stripped the gravel covering from the 7,000-foot bench already described and allowed the streams to cut sharp canyons across the area.

ROCKS.

The following table shows the sequence of rocks as observed in the district, the oldest at the bottom of the column:

Maximum observed thickness of rocks in the Mogollon district.

	Feet.
Quaternary:	
Gravels	700
Basalt dikes.	
Tertiary:	
Mineral-bearing veins.	
Intrusive andesite porphyry.	
Red sandstone and conglomerate	400
Andesite with dacite flows	600
Rhyolite tuff	400
Dike of tuffaceous rhyolite.	
Andesite	600
Rhyolite, coarsely spherulitic	1,200
Andesite and basalt	800
Sandstone	100
Rhyolite with quartz phenocrysts	700
Sandstone with andesite flow in lower part	400
Rhyolite and rhyolite tuffs	1,400
Rhyolite, minutely spherulitic	700+



GEOLOGIC MAP OF THE MOGOLLON DISTRICT, SOCORRO COUNTY, N. MEX.

Scale $\frac{1}{24,000}$

0 1/2 1 Mile

1000 0 1000 2000 3000 4000 Feet

Contour interval 200 feet

Datum is mean sea level

The sum of the maximum observed thicknesses amounts to 8,000 feet, of which 6,400 feet represents lava flows and pyroclastic rocks, and the remainder sedimentary deposits laid down by streams. This total is of course not a measure of the original thickness of the formations, as these rocks are not all present throughout the area. The rhyolites in particular are very uneven in thickness, and a flow may be lacking in one section and show a thickness of several hundred feet a short distance away. Moreover, there was considerable erosion at different stages in the upbuilding of the mass, and parts of the different flows have been removed. In many places exposed contacts show erosional unconformities, indicating that an extremely rugged topography was developed between periods of volcanic activity. Graton[5] considers that the lavas were probably extruded in the early part of the Tertiary period.

No petrographic examination of specimens collected in the field has yet been made, and the following descriptions are based principally on the writer's field notes. It is probable that some modifications, particularly in nomenclature, will be required when the rocks are studied with the aid of the microscope.

The oldest rock exposed in the district is a rhyolite of light purple color that breaks with a platy fracture. It is commonly flow-banded and in places shows numerous small spherules. More rarely it is slightly porphyritic and carries small crystals of milky feldspar and biotite in a glassy base. A characteristic feature of the rock is the presence of ellipsoidal cavities as much as 3 inches in length lined with small quartz crystals. These cavities are parallel to the lines of flow. In places inclusions of andesite are found, but these are much rarer than in the younger rhyolites. Several flows are present, and beds of white tuff mark periods of explosive activity. The maximum thickness as exposed in Cooney Box is about 700 feet. This rhyolite is also well exposed in Whitewater Canyon, south of the area mapped, but does not crop out on Silver Creek.

The formation above this rhyolite consists of alternate thin flows of rhyolite and beds of rhyolite tuff with a few lenses of red and purple or, more rarely, green sandstone. The flows, which are best exhibited along the power-plant road, in the southwestern part of the area, consist of a red, very porphyritic rock with numerous and prominent crystals of biotite and feldspar. As a rule the volume of the phenocrysts equals or exceeds that of the groundmass. The feldspar crystals are in part milky white and in part glassy, with minute striations characteristic of plagioclase. Large poikilitic feldspar crystals were observed in places. According to Graton,[6] the feldspar consists of about equal amounts of orthoclase and of plagioclase that ranges from andesine to labradorite. Quartz is usually

[5] Graton, L. C., op. cit., p. 194.

[6] Graton, L. C., op. cit., p. 192.

inconspicuous or not visible to the eye, but in a few of the flows quartz phenocrysts are prominent and the rock resembles the next younger of the rhyolites. Quartz intergrown with feldspar is a common feature. The groundmass is generally glassy in appearance; only rarely was a spherulitic texture observed. A partial analysis of the rhyolite from the canyon wall directly above Cooney, made by W. T. Schaller, shows the rock to be richer in soda than is normal, and it is therefore designated soda rhyolite by Graton.[7]

Partial analysis of soda rhyolite from canyon above Cooney, N. Mex.

SiO_2	67.83
CaO	2.10
K_2O	5.46
Na_2O	3.30

From Graton's description and the analysis it would appear that quartz latite is the name most applicable to this rock. This name, however, is not used in this preliminary paper, because it is not yet known whether this is the only quartz latite of the series or whether the high soda content and the presence of abundant plagioclase characterize all the silicic rocks of the district.

This rhyolite appears to have been more fluid than the others and has spread out in thinner sheets. Probably none of the individual flows in this formation exceed 100 feet in thickness, and the average thickness appears to be much less. The tuffs resemble the lavas in mineral composition but show rather more weathering and are white and pink instead of reddish. Many of them contain pebbles of andesite. The tuff beds are of about the same thickness as the flows.

The maximum thickness of the formation within the area mapped is 1,200 feet, in the southwest corner of the area. Neither the base nor the top is here exposed. On the north wall of Whitewater Canyon, a short distance to the south, there is a thickness of 1,400 feet above the lower rhyolite, and an unknown amount has been removed by erosion. To the north the thickness is much less, and on the north wall of Cooney Canyon, between the lower rhyolite and the sandstone above, there is a thickness of only about 700 feet.

After the deposition of these rhyolite flows and the accompanying tuffs, there was a period of erosion during which deep canyons were cut. Remnants of these canyons can be seen in the steep contacts of rhyolite tuff and sandstone on the sides of Gold Dust Gulch and Houston Canyon. As shown in the walls of Houston Canyon, a steep-sided canyon over 300 feet in depth was cut out before being filled with sandstone. A change in the character of the streams caused the filling of this canyon and the covering of a wide belt in

[7] Graton, L. C., op. cit., p. 192.

the western part of the area with sandstone containing lenses of conglomerate. The deposition of sandstone was interrupted once by a flow of andesite, 40 feet thick, with phenocrysts of biotite and pyroxene, and later by the deposition of white rhyolitic tuff, about 25 feet thick. The sandstone is commonly red to deep purple and nearly everywhere shows cross-bedding. Except for the rather rare conglomeratic phases it is fine grained and made up largely of small fragments of feldspar. The irregular dips that characterize the formation are, in part at least, the result of deposition on a sloping surface, as in the north wall of Mineral Creek canyon, opposite the Cooney mine, where sandstone dipping 15°–30° to the east and northeast overlies rhyolitic tuffs that dip 10°–15° to the northwest, and is itself overlain by andesite tuffs with sandstone beds which show easterly dips of 5°–8°.

The thickness of the sandstone exposed exceeds 400 feet in Houston Canyon. At the edge of the old canyon referred to above the thickness changes from 200 feet to about 20 in a distance of less than 300 feet, and 200 feet farther east the sandstone disappears altogether. Near the mouth of Silver Creek over 500 feet is exposed. The thickness decreases northward to about 100 feet on Silver Peak. It also decreases eastward, and within a short distance the sandstone disappears, although the change is not as abrupt as in Gold Dust Gulch.

The next flow of rhyolite apparently occupied part of the valley in which the sandstone was being deposited, its maximum thickness being nearly coincident with the thickest portion of the sandstone. The distinguishing field characteristic of this lava is the presence of visible quartz. Commonly the rock shows prominent quartz and feldspar, apparently both orthoclase and plagioclase, and subordinate biotite, in a groundmass which is glassy in appearance, and in a few localities shows spherulitic texture. Tuffs having about the same mineral composition are of common occurrence. At the base of the series, quartz is less prominent and the rock closely resembles the older rhyolite below the sandstone. The steep contacts exposed on the northern wall of Gold Dust Gulch show that this lava in part occupied a valley eroded in the earlier tuff and rhyolite.

This quartz-rich rhyolite forms the prominent cliffs near the mouth of Silver Creek and the summit of Silver Peak, in the northwest corner of the area. It is also present in considerable thickness on the ridge between the power-plant road and Houston Canyon, south of the Confidence mine. Here, however, the formation appears to be predominantly tuffaceous. In the cliffs of Silver Creek canyon the quartz-rich rhyolite in thick flows, showing rough columnar structure and separated by thin beds of tuff, has a total thickness of 600 feet. On Silver Peak there is about 500 feet remaining, and east of Houston Canyon the alternate tuffs and flows are about 700 feet thick. The thickness is very irregular. Between the sections in Silver Creek and east of Houston Canyon the formation is lacking entirely, and half a mile east of the thickest part of the Silver Creek section only about 100 feet is present. A similar thinning out is observable east of Silver Peak, in the northern part of the area.

Deposition of the sandstone continued after the eruption of the quartz-rich rhyolite. In this upper portion, however, there is much coarse conglomerate with large pebbles of quartz rhyolite and of the older biotitic rhyolite. In the north branch of Houston Canyon, just under the Silver City road, the quartz-bearing rhyolite is lacking and the conglomerate with pebbles of this rhyolite rests, without apparent break, on fine-grained cross-bedded sandstone. In Cooney Canyon a thin flow of andesite occurs in the conglomerate.

The conglomerate is overlain by the first of the series of andesite lavas that are so prominent in this region. The following petrographic description is quoted from Graton:[8]

Plagioclase feldspar is the principal constituent. It is of the composition of either andesine or, less commonly, oligoclase. Phenocrysts of pyroxene were present but are now much decomposed, the usual products being quartz, chlorite, and iron ore (magnetite?). Some of this material may originally have been hornblende or even olivine. The groundmass consists principally of minute plagioclase laths with profuse grains of magnetite, now much altered to limonite. Glass is much less common than in the soda rhyolite. Alteration, while of the same character as that which has affected the soda rhyolite, has had a much more pronounced effect on the andesite. It many places the rock has been greatly bleached to a greenish-gray color; quartz has formed plentifully in the groundmass and has replaced the calcite of many of the amygdules. Calcite is abundantly developed in places, however. Where the most alteration has taken place pyrite, chalcopyrite, and bornite are present in scattered grains and in tiny veinlets. The general composition of the rock is expressed by the following partial analysis of a specimen from the Cooney mine, made by W. T. Schaller:

Partial analysis of latite from the Mogollon district.

SiO_2	48.00
CaO	7.72
K_2O	3.28
Na_2O	1.95

It is difficult to account for the amount of potash shown by the analysis, as by far the greater part of the feldspar appears certainly to be plagioclase. The analysis was repeated and found correct. Probably most of the so-called andesites of this region are in reality latite, and the potassium is probably contained in the groundmass.

The complete alteration of the ferromagnesian phenocrysts makes field determination of the andesites very uncertain. The lower series appear to be more nearly basaltic in character than those above the rhyolite flow. In the lower series augite occurs nearly everywhere in

[8] Graton, L. C., op. cit., pp. 192–193.

prominent phenocrysts, and a few of the flows appear to have contained phenocrysts of olivine. Rarely small altered crystals of biotite may be observed. The only good exposure of the lower andesite is in the south wall of Mineral Creek canyon above the Cooney mine. Here a series of thin flows with beds of breccia and agglomerate and a few thin beds of reddish-purple feldspathic sandstone occupy the lower 700 feet of the canyon wall. In the Last Chance mine the rock forms the footwall of the vein for a vertical distance of over 800 feet. Less than a mile to the northeast, however, the andesite is missing and the overlying spherulitic rhyolite rests directly upon quartz-bearing rhyolite. In many places there is a few feet of reddish-purple sandstone above the andesite, indicating a short period of quiescence before the outflow of the spherulitic rhyolite, next to be described.

The next in the series, a rhyolite with well-marked spherulitic texture, seems to have flowed out in a very viscous condition and solidified in the form of a rather flat mound. The maximum thickness observed was at a point south of the area studied in detail, near the junction of Whitewater Creek and South Fork, where at least 1,200 feet is exposed. On the south edge of the area mapped the thickness does not exceed 1,000 feet. A mile to the north, in the Last Chance workings, the flow is 800 feet thick. The Little Fanney workings, on the south side of Fanney Hill, show a thickness of 600 feet. On the north side of the same hill the thickness decreases sharply until at a point 1,000 feet west of the Cooney mine a few feet of rhyolitic tuff is all that remains. Farther west only a thin bed of sandstone with rhyolite fragments separates the upper and lower andesites. On the north side of Mineral Creek there is a thin bed of rhyolitic tuff which is believed to mark the same horizon. To all appearances this mass of rhyolite represents a single flow. The only evidence to the contrary is the presence of rhyolite breccia on the point above the Eberle mine, about 150 feet lower than the upper contact. It is possible, however, that this is merely a flow breccia due to premature solidification of part of the flow.

The distinguishing characteristic of this rhyolite is its spherulitic texture, and it is the only member of the rhyolite series in which spherulites are at all prominent. Most commonly the rock shows closely crowded light-pink to white spherulites in linear arrangement in a rather glassy groundmass of a delicate light-purple shade. The spherulites are usually from a quarter of an inch to more than half an inch in diameter and show a radial structure. In places they are so closely packed as to form over half of the rock mass; elsewhere layers composed largely of spherulites alternate with flow-banded rhyolite in which spherulitic texture is subordinate. The viscous nature of the flow resulted in the formation of cavernous open spaces before complete solidification. The larger of these spaces show clusters of spherulite-like bodies from a fraction of an inch to 2 inches in diameter. Some of these look almost like clusters of grapes; others have a reniform appearance. They consist of a thin shell of lithoidal matter lined with crystals of bluish quartz. Quartz crystals also line small cavities in the rock mass itself.

Obsidian is not common but was observed in places. A very striking variety of the rock was observed on the ridge northeast of the limekiln, where a dark-brown glass of resinous appearance is thickly studded with pink spherulites.

Porphyritic crystals are found here and there in the flow-banded portions of the rock. Feldspar is the most common, and two kinds were observed—stout milk-white crystals and thinner glassy crystals, many of which are striated. The milk-white variety is by far the commoner. Biotite is also present in small amount, but quartz phenocrysts were rarely observed.

In many places the upper part of the rhyolite to a depth of a few inches is dark purple, in contrast to the light brown or pink of the main rock mass. This difference appears to be due to inclusions of minutely divided foreign matter, a sort of scum carried on the surface of the molten rock. Small inclusions of andesite are also numerous near the upper surface of the flow.

Although a few feet of sandstone containing rhyolite fragments was observed in places above the rhyolite, there does not appear to have been any considerable erosion prior to the next period of andesite flows, and, except as modified by faulting and recent erosion, the lenticular shape of the rhyolite body represents the original form of the flow.

After the rhyolite extrusion the country was covered by successive thin flows of andesite. The eruptions were accompanied by considerable explosive action, and in certain places breccias and agglomerates exceed the lavas in volume. Some of the breccias have been reworked by water and consist of subangular andesite blocks in a sandy matrix. Thin beds of sandstone also occur.

Owing to the complete decomposition of the ferromagnesian minerals, the andesites of this series are difficult to distinguish from those above and below. On the whole, however, they appear to be less basaltic than the lower series. Augite is the most prominent phenocryst, but many of the flows also contain small crystals of biotite. Olivine appears to be lacking. In other respects the rock closely resembles the andesites below the spherulitic rhyolite.

The series is thickest in the northern part of the area, where the rhyolite is represented only by a few feet of tuff. Here it is about 600 feet thick. In the southern part, where the rhyolite is much thicker, not over 300 feet of andesite is present. Overlapping of the andesite flows on the mound of rhyolite is shown in the south wall of Mineral Creek canyon, where thin beds of sandstone containing broken spherules derived from the rhyolite occur between the andesite flows.

A small rhyolite dike crosses the central part of the area, extending northward from the Last Chance fault to a point a short distance west of the Trilby mine, a distance of a little over a mile. This dike ranges from 5 to 20 feet in width. Secondary silicification makes field determination difficult, but the material of which it is composed appears to be a rather siliceous flow-banded rhyolite, intensely brecciated. The dike cuts both the spherulitic rhyolite and the overlying andesite and is similar in composition to the tuff above. It may occupy a channel through which the tuff was erupted.

Above these andesites is a bed of white rhyolitic tuff. This bed appears to be persistent throughout the area, although it varies greatly in thickness, from a minimum of less than 10 feet to a maximum of about 400 feet. Its glaring white color makes its conspicuous on steep bare slopes, as in the eastern part of Mineral Creek canyon. Generally, however, where not protected by overlying harder rocks or rendered more resistant by later silicification, it forms gentle slopes. This tuff consists of small fragments of a glassy flow-banded rhyolite, similar in appearance to the less spherulitic parts of the rhyolite next below, in a white fine-grained, somewhat kaolinized matrix. In places, particularly near the veins, later silicification of the matrix has given the tuff the appearance of a very siliceous rhyolite flow. In most places, however, a faint bedding is observable. The tuff is nearly everywhere capped by a few feet of red sandstone containing small rhyolite pebbles.

The youngest effusive rocks of the area are andesites, a series of flows from 250 to 600 feet thick. As with the lower flows, field determination is difficult, owing to the alteration of the dark silicates. So far as could be observed, however, this series is more silicic than the older andesites. As in the lower andesites, pyroxene is the most common phenocryst, but amphibole is prominent in several flows. Otherwise the rock for the most part closely resembles the andesite above the spherulitic rhyolite. A characteristic feature of the upper andesites is the presence of a flow of dacite near the top of the series. This rock is dense and dark reddish brown and shows comparatively few amygdules. It contains small corroded crystals of quartz, which appear almost black against the dark background of the rock, and small crystals of biotite and glassy feldspar. Within this series of flows, about 50 feet above the top of the rhyolite tuff, there is in many places a thin bed of red sandstone containing small fragments of rhyolite, indicating that a rhyolitic eruption, not otherwise represented in the Mogollon area, again broke the sequence of andesitic outbursts.

Sedimentary rocks to a considerable thickness were laid down upon the surface of the upper andesite. They consist of conglomerate and sandstone with a few lenses of red shale. The conglomerates are best developed near the base but occur throughout the formation. They contain pebbles and subangular boulders of rhyolite and andesite, and the andesite is especially abundant in the lower portions. Some of the rhyolite pebbles resemble the spherulitic rhyolite beneath the latest andesite series. In the area mapped the conglomerate and sandstone series has a maximum thickness of about 400 feet and is dark brown to dark purple. To the north and northwest it appears to be much thicker, sandstone composes the greater part of the series, and the color is lighter, shades of pink and light brown predominating. Similar sandstone and conglomerate occur at the top of Cooney Peak at an altitude of 8,000 feet. Here they are capped by a thin flow of basalt.

A mass of intrusive andesite crops out in the valley of Silver Creek at the mouth of Dog Gulch. The outcrops, partly masked by talus, extend for 300 feet vertically above the creek on the north and to about the same height on the south. The rock is rather more coarsely crystalline than the effusive andesites and contains phenocrysts of hornblende, biotite, and glassy feldspar in a fine-grained feldspar-rich groundmass. In this rock, as in the effusive andesites, the ferromagnesian minerals are much altered. The intrusive cuts both the andesite series and the rhyolite tuff. Its age relation to the conglomerate is not certain. Possibly the eastward dip of the base of the conglomerate to the southeast of Mogollon, as shown in section C–C′, Plate XVI, may be due to doming caused by the intrusion. Both the intrusive andesite and the conglomerate are older than the faulting and subsequent mineralization. Andesite with a pronounced diabasic texture was found on the dump of the Cooney mine and was encountered in the new workings of the 1,100-foot level of the Fanney mine, which were not accessible at the times of visit. The relations of the rock to the other formations are unknown, but its texture and its small areal extent suggest that it is intrusive.[9]

A few dikes of basalt cut the older formations of the area. At one place a small basalt dike crosses a fault, and it is probable that all the basalt dikes in this district were intruded subsequent to the faulting and mineralization.

Gravel deposits of considerable thickness occur west of the scarp that forms the front of the Mogollon Range. In the area mapped

[9] According to Scott (op. cit., p. 5) the diabasic andesite is a flow older than the lower of the three andesite series described above.

these deposits appear only in a small strip in the northwestern portion, where they are faulted against the rhyolite tuffs. They consist of roughly consolidated, rather coarse gravels with lenses of sandy material. The bedding is coarse and in general obscure. In most places a gentle westward dip is observable. Flows of basalt occur in a few places between the beds of gravel. The thickness of the gravel, as measured from Mineral Creek to the top of the mesa to the north, is about 700 feet. The pebbles include lavas of various types, but basalt and basaltic andesite appear to predominate.

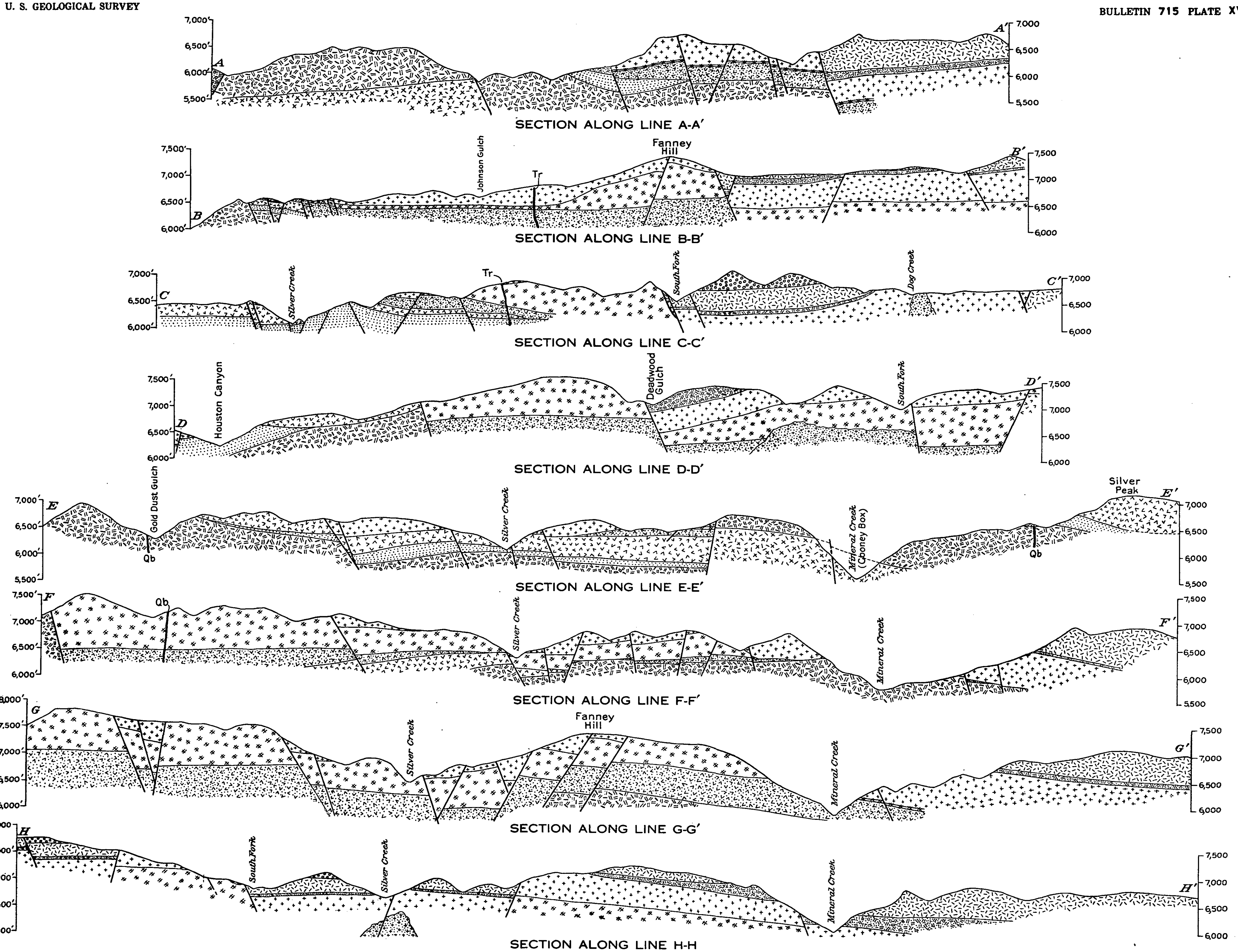
STRUCTURE.

The present attitude and to some extent the relative positions of the rock formations are due to complex normal faulting, which has brought blocks of the younger rocks of the series into juxtaposition with the older. Two periods of faulting are discernible—one of unknown date but subsequent to the deposition of the conglomerate and the intrusion of the andesite porphyry and prior to the intrusion of the later basalt dikes and deposition of the gravels, and the other comparatively recent, for it has determined the present topography and has brought the recent gravels into contact with the older rocks.

The faulting of the first period was much the more widespread and complex. The area was broken up into a great number of irregular blocks, bounded by faults that follow two main directions—one between north and north-northeast and the other between west and northwest. Nearly all the fault fissures in the area are occupied by veins, consequently they are more easy to trace than is usual in an extensively faulted district of this nature. As will be seen from the geologic map and Plate XVII the most persistent fault in the area is the one that crosses the eastern portion from north to south, known as the Queen vein. The fissuring along the Queen vein is not simple, and in many places the total throw is distributed among several nearly parallel faults. This fault is very persistent, however, and has been traced not only across the area mapped but for a distance of 3 miles to the north and 2 miles to the south, a total distance of nearly 7 miles. The fault plane dips steeply to the east. The amount of displacement varies from place to place, as the territory on each side is likewise broken up into blocks by faults at angles to the strike of the Queen fault, with varying amounts of throw. As shown by sections A–A′, B–B′, C–C′, and D–D′, Plate XVI, the vertical displacement along the Queen fault is from 500 to more than 1,000 feet. Other north-south faults of considerable magnitude lie to the east of the area, between Mogollon and the crest of the range. Near the western border of the area is another zone of northerly faulting, less well defined than the Queen fault. In the southern part, from the southern border of the area to the Confidence vein, this appears as a single fault of considerable throw, which brings the spherulitic rhyolite against the much earlier biotite-bearing tuffaceous rhyolite. In this portion it is chiefly remarkable as being one of the few fractures in the areas along which there was no important mineralization. Between the Confidence vein and Silver Creek there is a complex fracture zone about half a mile in width, which consists of blocks bounded by minor northerly faults, and has been depressed relatively to the blocks on either side. The surface rocks are not well enough exposed in the flat interstream area north of Silver Creek to permit tracing with any certainty the faults that compose this complex series, but a number of similar small faults appear on the northern edge of the plateau. Thence northward the system appears to be represented by a single fault, known as the Great Western, which has a northeasterly strike and dips to the southeast. The maximum vertical displacement along this portion of the fault exceeds 600 feet. The faults with dominantly westerly and northwesterly strikes are for the most part best defined close to the Queen fault and tend to disappear toward the west. The most persistent of these, the Last Chance-Confidence fault, is, however, traceable for nearly 2 miles. The structure produced by block faulting in this part of the area may be likened to two flights of steps, one leading down from the north and the other from the south, the lowest step, which is common to both flights, being represented by the block north of the Maud S. fault, which has a total vertical displacement of about 1,000 feet below the highest block on the north and 1,200 feet below the highest on the south. The same structure is repeated east of the Queen fault, though here the faulting appears to be less complex, and the lowest block includes the conglomerate-covered ridge between the town of Mogollon and South Fork.

A peculiar feature of the faults with westerly strike is the marked change in strike which they exhibit close to the Queen fault. On nearly every fault that could be followed at the surface there is a marked tendency toward parallelism close to the Queen and increasing divergence in strike a short distance away.

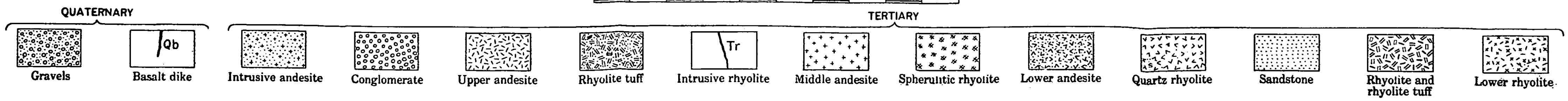
The general appearance of the entire fault system of the district, as shown in Plate XVII, indicates that the northerly and westerly faults were formed at the same time. The Queen fault appears to be the site of the principal fissuring, and the faults branching out from it on either side represent subsidiary fissuring. It is thought probable that this branching is due to faulting under light load, and that if the cover had been heavier the change in strike of the minor faults close to the Queen fault would have been less pronounced and the junctions would not be complicated with minor cross faulting.



GEOLOGIC SECTIONS ACROSS THE MOGOLLON DISTRICT, N. MEX., ALONG LINES SHOWN ON MAP, PLATE XV

Scale $\frac{1}{24,000}$

0 ½ 1 Mile



SKETCH MAP SHOWING OUTCROPS OF FAULTS IN MOGOLLON DISTRICT, N. MEX.

East of the Queen vein the change in strike of the fault planes close to the Queen is less distinct, probably in part because these faults are less mineralized and consequently less easy to follow. So far as observable these fault planes turn sharply to the north as they approach the Queen, whereas those west of the Queen bend to the south.

The relative vertical displacement of the different blocks is shown in the accompanying sections. The horizontal displacement or heave is, however, difficult to determine. It is evident that in a fault block which is bounded by inclined planes and in which the vertical displacement decreases away from the major fault some horizontal movement must have taken place. The grooves and slickensides on the walls of the faults indicate that the horizontal component was less than the vertical, for these grooves stand at angles of 60° or greater in the plane of the fault. A rough guide to the amount of horizontal displacement is found in the offsets of the small rhyolite dike that crosses the central part of the area. This dike shows offset between 100 and 700 feet in the group of faults between the Maud S. and Trilby mines. These offsets, however, would afford a true measure of the horizontal displacement only if the dike were vertical, and as it is notably irregular along its strike its probable irregularities in dip lessen its value as a means of measuring horizontal displacement.

Later faulting seems to have been confined almost exclusively to the great fault that bounds the front of the range. The outcrop of this fault is everywhere concealed by talus, but the section revealed on Mineral Creek canyon just west of the mouth of Cooney Box shows partly consolidated gravels abutting the steep rhyolite cliffs, with only 200 or 300 feet of talus-covered ground intervening. The physiographic evidence of the fault is unmistakable. The mountains end in a sharp and well-defined cliff which, except where broken by the stream canyons, extends in a nearly straight line for 10 miles from Deep Creek on the north to Little Whitewater Creek on the south. The difference in topography on the two sides of the range is additional evidence of faulting. The streams flowing westward from the crest have cut deep canyons throughout the greater part of their courses. These canyons are broadly V-shaped near their heads but become narrower to the west and finally close to the narrow clefts or "boxes" through which the streams issue from the range. The eastward-flowing streams, on the other hand, have lower grades, and the interstream areas are flat or gently sloping.

A rough estimate of the vertical displacement along this frontal fault can be made on the assumption that the nearly flat interstream areas in the Mogollon district represent approximately the surface from which the gravels east of the fault have been eroded, those on the west owing their preservation to downthrow by faulting. As stated previously, these flat interstream areas are a prominent feature of the topography in the immediate vicinity of the Mogollon district. The change from the steep walls of the transverse canyons to the nearly flat upland is everywhere sharp, and even the minor tributary canyons show very little gradation. This upland was cut on rocks of greatly different resistance, and so must represent a surface at one time reduced nearly to base-level. As the faulting and consequent relative elevation of this region took place after the deposition of the gravel that now abuts against the fault on the west, it is evident that the gravels must have had a much greater extent toward the east, and therefore that this bench represents very closely the old valley surface upon which the gravels were laid down. East of the region covered by the map the rising ground of the interstream areas marks the limit of this old valley. The benches range in altitude from 6,700 to 7,600 feet. The base of the gravel beds west of the fault is not exposed, but on Mineral Creek, close to the fault, they occur at an altitude of 5,400 feet. The minimum vertical displacement must therefore exceed 1,300 feet by whatever thickness of gravel may lie below the valley of Mineral Creek.

Before this later faulting took place the fault fissures of the older series had been healed by the introduction of the veins. Consequently, rejuvenation of the older faults does not appear to have been of much importance. Nevertheless, there is evidence of renewed motion on many of them.

Along a portion of the Pacific vein there is heavy gouge of apparently postmineral age, and in the western part of the Last Chance workings a transverse fault accompanied by postmineral gouge cuts but does not visibly offset the vein. Apparently the only effect of the later faulting has been to cause a slight readjustment of a few of the older fault blocks close to the frontal fault. This renewed motion, small as it was, elsewhere than along the main fault, was of considerable economic importance in that it appears to have provided channels through which the oxidizing solutions had better access to the ores than elsewhere along the veins.

Tilting has to some extent accompanied all the faulting. The amount has probably not been great, although the irregular contacts between the flows and the sediments and the extensive cross-bedding of the sandstones make the determination of the amount of tilting a difficult matter. On the whole, the older members of the series seem to show higher and more irregular dips than the younger, a difference which indicates some movement prior to the principal period of faulting. The andesite intrusion at the mouth of Dog Gulch seems to have caused a gentle doming of the overlying formations. Close to the major faults, particularly the Queen, the dips of the flows and beds are in places steeper than elsewhere, owing to drag along the faults. In the western part of the area the upper contact of the oldest rhyolite dips to the west. This may be due to erosional unconformity, to earlier tilting, or to the drag of the recent fault bounding the range. West of this fault the gravels show a gentle westerly dip.

It is probable that a more detailed physiographic study of the whole range would show that the effect of the recent faulting was not simply the relative depression of a block on the west of the fault, but involved a tilting of the whole mass now forming the Mogollon Mountains, with relative elevation on the west and depression on the east.

The faulting of both periods probably took place under light load. The later faulting affected the unconsolidated gravels, and its topographic expression has been only slightly obscured by later erosion. In the older series the feathering of the faults near their junctions and the dying out of many of the transverse series at short distances from the main north-south fault is evidence of movement under light load. Although the geology of the range must be studied in detail before a definite statement can be made, it is probable that the surface at the time of the earlier faulting was not over a few hundred feet above the youngest formation now exposed in the Mogollon district.

The cause of the faulting may be assigned to local overloading of the crust due to the transfer of great masses of igneous rock material from the interior to the surface of the earth.

RECENT GEOLOGIC HISTORY.

The surface prior to the first period of faulting was probably a fairly flat lava plain. Faulting broke this plain into irregular segments and gave opportunity for renewed erosion which continued until the irregular mountain mass was reduced to a mature topography. On the western flank of the range was a broad valley which later became filled with gravel to a depth of several hundred feet. The next geologic event was the formation of the great fault which defines the present front of the range. This faulting gave another impetus to erosion on the west side of the range and began the cycle in which the present topography has been carved out. As the rejuvenated streams flowing westward began cutting their canyons the easily eroded gravel remnant was removed, leaving the nearly flat bench which to-day gives the interstream areas of the Mogollon district so striking a contrast to the steep-walled canyons below. On reaching the harder rock the streams cut more slowly, and as yet they have only had time to cut narrow canyons near their points of emergence from the range. The courses of the main streams that crossed the rock bench were determined by the preexisting topography, and consequently their canyons now cut rocks of all degrees of hardness without adjustment to structure. Their tributaries, however, which have been developed for the most part since the erosion of the gravels on the bench, show some slight accord with the rock structure. Houston Canyon, in the southwestern part of the area, owes its development to erosion in the soft sandstones, and the same is true of Bluebird Gulch. In the south-central to northeastern part of the area there is a line of tributary gulches roughly parallel to the Queen fault and generally a short distance to the east. These, from south to north, are Deadwood Gulch, Graveyard Gulch, two gulches entering Mineral Creek from the south and north near the old Queen mine, and a gulch draining northeastward in the northeast corner of the area. All these gulches probably owe their origin to easy erosion in the fractured zone bordering the Queen fault. This zone of easy erosion, however, seems to have been of shallow depth, and these gulches, which are now cutting resistant quartz veins and the silicified areas near the vein walls, show a canyon topography comparable to the main streams. Pauses in the process of canyon cutting are marked by secondary benches in the canyon walls. The largest and oldest of these is preserved only in remnants along the edges of the present canyons. On the south side of Silver Creek canyon this bench, cut in the resistant spherulitic rhyolite and the overlying andesite, occurs at an altitude of 6,700 to 6,800 feet and has a maximum preserved width of about a quarter of a mile. On the north side of the canyon the bench does not appear, but the possible remnant of a still older one at an altitude of 7,100 feet is found on the point south of Fanney Hill. The only bench of similar nature in Mineral Creek canyon is found on the north wall, just south of Silver Peak, at an altitude of 6,350 feet. The well-defined bench on the south side of Silver Creek canyon is at about the same altitude as the two rhyolite hills that guard the mouth of the canyon. Probably the uncovering of the dome of resistant rhyolite retarded erosion to some extent. Other less well-defined benches occur in places along the canyon walls but are not sufficiently extensive to show on the topographic map. Here and there along Mineral and Whitewater creeks there is a little water-worn gravel at about 50 feet above the present streams.

ORE DEPOSITS.

The ore deposits of the region are all in veins that are closely connected with the faults. Although veins along the faults are a feature of the country for a considerable distance from the mining district, the deposits which have so far proved productive occupy only a small area bounded by the Last Chance-Confidence and Pacific veins on the south and west, the Queen vein on the east, and the Cooney mine in Mineral Creek canyon on the north, an area of less than 2 square miles. The most productive veins have been those following the lateral series of faults, which branch out from the Queen toward the northwest, particularly the Last Chance-Confidence, the Maud S., and the Little Fanney. With the exception of the Pacific vein and its northward extension into the South Alpine claim, the group of mineralized faults in the west has not been productive. Small ore bodies have been developed in places along the Queen vein, but over the greater part of its course this vein appears to be barren. The veins east of the Queen vein have as yet shown no ore.

The veins are for the most part well defined and form prominent outcrops. In places the resistant quartz veins form walls standing out above the surrounding surface. In a few places along the strike of the veins mineralization is lacking, and only the fault lines mark the direction which must be followed. Nearly everywhere along the fissures, however, there is some slight mineralization. The veins vary greatly in width from place to place and are not constant in dip or strike. Near the Queen vein all the branch veins show a sharp change in strike, indicating that the fissures were contemporaneously formed. Although the association of veins with major fault planes is nearly universal, there are a few places where a vein leaves a major fault fissure for short distances and follows minor fissures in the foot or hanging wall. This indicates that the mineralization was not contemporaneous with the principal faulting, although it probably followed the faulting closely. Mineralization was contemporaneous throughout the veins. Where intersections of veins have been exposed, as those of the Pacific and Confidence in the main level of the Confidence mine and the Last Chance and Queen in the 700-foot level of the Last Chance mine, the two veins show a blending of their filling and structure. Near the intersections are commonly also numerous small veins linking the two larger ones. This shows particularly well on the surface at the intersection of the Independence and Fanney veins with the Queen.

The veins exhibit a considerable uniformity of mineral content. Quartz and calcite are the principal gangue minerals, and a little adularia is also present. Fluorite is plentiful in many places. In most veins the principal valuable mineral is argentite, although pyrite, chalcopyrite, bornite, a little galena, and probably small amounts of sphalerite also occur. In a few veins copper sulphides, principally bornite, chalcopyrite, chalcocite, and tetrahedrite, predominate. Oxidation is shallow and irregular in extent, and where found at any considerable depth below the surface appears to be dependent on recent movement along older fissures. Sulphide enrichment has probably occurred to considerable extent, but to what proportion the rich sulphide ores are dependent on such enrichment is not yet clear. Cerargyrite and probably other silver haloids, native silver, rare free gold, malachite, azurite, limonite, "copper pitch ore," cuprite, and manganese oxides are present in the oxidized ore. The chalcocite and covellite and part of the argentite, pyrite, and native silver appear to be due to sulphide enrichment, but a part of the argentite, most of the pyrite, and all of the bornite, chalcopyrite, tetrahedrite, and galena are apparently primary.[10]

The earliest of the gangue minerals is in most of the veins a minutely crystalline quartz, which in places shows a delicate banding and is similar to chalcedony in appearance and elsewhere is massive and porcelain-like, resembling hornstone. In some of the veins this quartz appears to have been brecciated before the introduction of the later quartz and calcite. Sulphides are rarely found in this fine-grained quartz. The deposition of the chalcedonic quartz was followed by the main period of mineralization, in which quartz and calcite were deposited alternately and together. There appears to have been much overlapping, and intimate intergrowths of the two minerals are common. The quartz pseudomorphs after tabular calcite apparently belong to this phase. Elsewhere a rough banding is observable. In most places quartz appears to have been the earlier of the two, and the deposition of the greater part of the sulphides accompanied the beginning of this stage of quartz deposition. The sulphides, particularly in the argentite veins, were commonly deposited in a band of crystalline quartz surrounding silicified fragments of the wall rock or fragments of the earlier chalcedonic quartz. Sulphides are only rarely found in association with calcite. The lamellar calcite and intergrown quartz and the quartz pseudomorphic after calcite appear to represent some of the later stages of deposition. Fluorite was likewise one of the later minerals to be deposited. The fluorite is light green to colorless or, very rarely, purple. In a few crystals there are well-defined zones marked by narrow brown bands. Sulphide minerals were deposited to some extent throughout this period. In ore from the Cooney mine chalcopyrite crystals were found in association with delicate blades of calcite resting on fluorite. Apparently the last stage of vein filling was marked by the deposition of coarsely crystalline calcite, largely manganiferous and barren of sulphides. This calcite occurs in places in the productive veins and is the principal mineral found in the barren veins east of the Queen.

[10] Besides the ore minerals mentioned above Scott (op. cit., p. 10) mentions bromyrite and stromeyerite.

Mineralization of the wall rock is not a prominent feature. Fragments included in the veins are largely silicified and have served as nuclei for the deposition of the sulphides. Where andesite forms the wall it is in places penetrated by pyrite for a short distance from the vein, and, particularly in the veins rich in copper minerals, the rock is cut by minute veinlets carrying quartz and calcite with bornite and chalcopyrite. The rhyolites are practically free from pyritization, except for the rare replacement of biotite plates by pyrite. The extent of rock alteration dependent upon the vein-forming process must be determined by future microscopic investigation. So far as can be judged from hand specimens, the rhyolite is only slightly affected, but the andesite appears to have suffered widespread alteration. The dark silicates of the andesite are almost completely altered, and the amygdules contain calcite and quartz. There appears to be in places considerable calcitization in the rock itself. The alteration of the ferromagnesian minerals is probably due chiefly to hydrothermal action rather than weathering, for the basalt dikes of postmineral age are comparatively fresh, and the andesites on the interstream plateau, which have been much longer exposed to weathering, are not noticeably more altered than those that crop out in the more recent canyons.

The rhyolites near the veins show more or less secondary silicification. This is most strikingly evident in the rhyolite tuff, in which the matrix is in places almost completely silicified. The feldspars of the massive rhyolite show, near the veins, a peculiar cavernous alteration, apparently the result of replacement by quartz with decrease in volume.

The zone of oxidation is shallow and irregular, although patches of oxidized ore have yielded considerable high-grade ore. In most of the veins sulphide ores have been stoped close to the surface. In a few places, however, oxidation has proceeded to a considerable depth, notably in the western ore body of the Last Chance mine, where quartz with well-crystallized cerargyrite or other silver haloids and rare platy native silver, together with small amounts of azurite, malachite, and chrysocolla, occur on the 500 and 700 foot levels, while in the next ore shoot to the east sulphate ore was mined nearly to the surface. Apparently this anomalous condition is due to the presence of a later fissure on the hanging-wall side which crosses but does not perceptibly fault the vein.

It is not yet certain how large a part sulphide enrichment has played in the formation of the ore bodies. Argentite appears in places as a filling of minute cracks, apparently later than the vein, and pyrite clearly of later origin is seen in places in fissures in the quartz. A kaolin-like mineral, probably kaolinite or halloysite, is found in places in the sulphide ore bodies, usually associated with vuggy quartz. This mineral has been observed in specimens from as great a depth as the 1,100-foot level of the Fanney mine. The minerals commonly indicative of sulphide enrichments in silver ores, such as proustite, pyrargyrite, polybasite, and stephanite, are not present in sufficient amounts to be visible to the eye, although there appears to be a little pyrargyrite in concentrates from the Last Chance ore. In the ores in which copper minerals predominate, however, chalcocite and a minor amount of covellite are present, commonly in close association with primary bornite, or tetrahedrite.

With the exception of the Deadwood, which receives the surface drainage of Deadwood Gulch, the mines are dry, and no pumping is required, even at depths below the present level of Silver Creek. This is probably due to the fact that the Queen vein and its branches tend to divert the ground water in the region east of the district. Although the Queen vein carried no water where it was cut in the 700-foot level of the Last Chance mine, a copious flow was encountered where the vein was tapped in the 500-foot level of the Fanney. The only ground water in the district, therefore, aside from what may seep through the Queen vein, is that derived from the small area west of the Queen.

The outcrops of the productive veins were subject to stream erosion prior to the later faulting and were later buried under a thick capping of gravel. Faulting and renewed erosion have caused a very rapid lowering of the water level. Consequently it is possible that sulphide enrichment has played an important part in the ore formation only where favorable conditions, such as later fracturing and minor post-mineral faulting, were present.

A feature of the ore bodies indicative of some enrichment is the tendency of the ore shoots to show flat bottoms or poorly defined prongs projecting downward from the main ore body. This is particularly well shown in the Last Chance mine (Pl. XX). The vein material below the ore shoots is similar in nature to the ore but is below the limit of economic exploitation.

The ore shoots are large, commonly from 300 to 600 feet in drift length and about the same along the dip. The old upper stopes of the Fanney mine, however, indicate an ore body measuring about 1,500 feet along the strike and about 500 feet along the dip. The width of the ore in places exceeds 20 feet, but the usual width is from 5 to 15 feet. Here and there the best ore is found close to one or both walls. Many of the ore shoots show a nearly straight boundary on one side. In nearly every place where this was observed it could be correlated with a minor vein branching off from the main vein. As a rule widening of the vein is an indication of ore. In some places, however, swells in the veins were found to be in whole or in part filled with barren calcite.

A peculiar feature of the district is the extreme localization of the productive area. The only mines that have furnished any notable production—the Deadwood, Last Chance, Confidence, Pacific, Maud S., Fanney (including the Johnson and Little Charley), and Cooney—are all included in an area a little over 1 square mile in extent. Of the north-south veins in the western part of the area only the Pacific has been a producer. The Queen vein carries ore in places, but over the greater part of its course it is barren, though it is the largest and best-defined vein of the district. The veins west of the Queen have been the largest producers, but only those between and including the Silver Bar and the Last Chance-Confidence have been profitable. The veins east of the Queen consist at their outcrops almost entirely of barren manganiferous calcite, but a few assays showing a low tenor have been obtained in places.

This extreme localization may be due in part to differences in original distance from the surface. It is surmised that in veins such as these, formed at comparatively shallow depths, the limiting conditions of temperature and pressure causing ore deposition were largely dependent upon the distance from the surface and consequently that the zone of original ore deposition in the different veins occurred at different levels but in each at approximately the same distance below the surface as it existed at the time the ore-bearing solutions entered the fissures. As the faulting that controlled the position of the veins probably preceded vein formation by a short time only, and as this faulting was effected under a comparatively light load, it follows that the original outcrops of the veins were at considerably different altitudes, their position depending on the relative position of the fault blocks bordered by the veins. If the zone of original deposition was a comparatively narrow one and not far below the original surface, then the veins whose original outcrops stood the highest would have their original ore bodies in large part eroded away, those in which the surface was much lower would hold whatever ore was originally deposited in them at a depth not yet reached by either erosion or exploration, and only those in which the original surface was at an intermediate altitude would contain ore at a level now reached by erosion, which has uncovered the outcrop but not cut deep enough to carry away the greater part of the ore. Such veins, owing to their topographic position, are likewise those most favorably situated with regard to enrichment.

A more detailed study of the whole range will be necessary before the surface as it existed at the time of ore deposition can be reconstructed with any approach to accuracy. It is believed, however, that the original surface at the time of faulting was not greatly above the present upper sandstone and conglomerate. On the assumption that this surface was 600 feet above the base of this conglomerate, an attempt has been made to reconstruct sections of the surface as it existed at the time of vein formation. The accompanying sections (Pl. XVIII), drawn along the lines E–E′, G–G′, and H–H′ of Plate XV, show this reconstructed surface. Owing to the irregularity of the formations as deposited and the greater erosion in the western part of the area, the probable error is greatest in section E–E′ and least in section H–H′. Section G–G′ is taken through the productive part of the district, in the portion showing greatest development. The known productive portions of the veins as shown by development work lie in a zone over 1,000 feet thick, the upper surface of which is from 1,000 to 1,800 feet below the assumed original surface and the base from 1,900 to 2,500 feet below this surface. The outcrops of the veins west of the Queen are for the most part above this zone, and in the western part of the area, along the line of section E–E′, erosion has reached to greater depths.

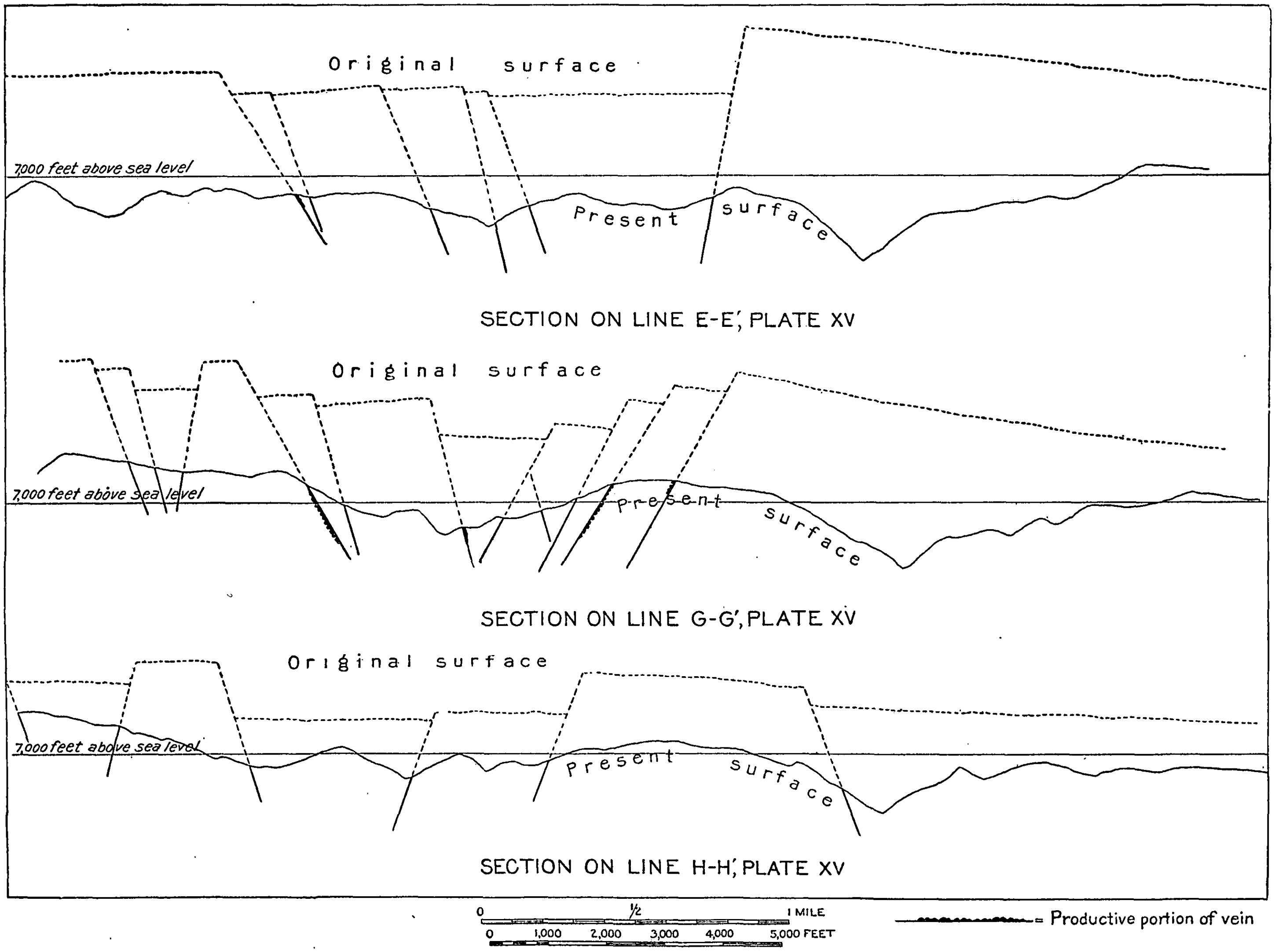
The mineralogic evidence is also in accord with the hypothesis outlined above. The barren veins east of the Queen vein are composed chiefly of coarse manganiferous calcite, which is believed to be the youngest of the gangue minerals and presumably was deposited under conditions of less pressure and lower temperature than were required for the sulphide-bearing quartz.

The westernmost deposits, such as the Pacific and South Alpine, have not proved productive in depth; the ore bodies are small, and the ore is widely oxidized. Copper minerals are likewise more prevalent than in the upper levels of the eastern group. The Cooney mine, which is the only mine yielding predominantly copper ore, lies at an altitude corresponding to the lowest portion of this hypothetical zone of original deposition.

It is realized that other conditions whose importance can not be evaluated, such as original width of the fissure and consequent freedom of migration of the solutions or distance from the original source, to a great extent controlled the original deposition of the ore, and this fact tends to weaken the foregoing hypothesis. It is believed, however, that this hypothesis affords the best explanation of the extreme localization of the productive veins of the district.

MINES AND PROSPECTS.

In this paper only short notes on the more important mines of the region are given, the detailed descriptions being reserved for the complete report.



SECTIONS SHOWING ASSUMED POSITION OF SURFACE IN MOGOLLON DISTRICT, N. MEX., AFTER FAULTING.

COONEY MINE.

The Cooney mine is in Mineral Creek canyon near the deserted town of Cooney. It has not been worked for several years, and the following description is quoted from Graton's report:[11]

The Cooney mine, sometimes called the Silver Bar, is owned by the Mogollon Gold & Copper Co. It is situated in the canyon of Mineral Creek just above Cooney Camp. The claim was among the earliest locations, having been staked by the discoverer of the district. In the early days the precious metals only were sought, the copper not being recovered by the extraction processes then employed. In recent years copper has been the chief product of value. The total output up to 1905 was stated to have been over $1,000,000. At that time the mine was idle, but production has since been resumed. The workings consist of an adit at the level of Mineral Creek which follows the vein to connect at a depth of 100 feet with an inclined shaft on the vein. Below the adit level there were in 1905 six levels, the lowest being 600 feet below the surface at the shaft. The shaft has since been extended to a depth of 760 feet. The mill equipment consisted of rolls, Huntington mills, Wilfley tables, and Frue vanners, with a capacity of 100 tons daily.

The predominating rock is andesite, much of it brecciated; soda rhyolite is present also, though the two rocks can not be distinguished underground. Both rocks show the alteration common in the district. The mine is located on the Cooney vein, which strikes about northwest and has an average dip of about 72° NE. It is a quartz-calcite-fluorite vein. * * * The principal ore body extends downward from the surface a little southeast of the shaft. It has been stoped through most of its extent. On the first level, 115 feet below the adit, the stope was 100 feet long and 12 to 15 feet wide; and on the second, 50 feet lower, the stope was of similar dimensions. On the third level, 50 feet below the second, the stope was 60 feet long and 25 to 30 feet wide, but not all the ore was mined out. It was at this point, especially in a stringer 3 to 8 inches wide lying in the hanging wall a foot or two from the main vein, that were found the finely crystalline specimens described on page 197, and consisting of calcite, fluorite, and quartz, with bornite, chalcocite, and chalcopyrite. This streak was very rich in copper. The stope on the third level was said to be at the junction of the Twig vein, which lies just northeast of the Cooney vein, but the writer was unable to observe any junction. A crosscut to the northeast revealed, about 35 feet from the Cooney vein, a narrow streak carrying calcite and bornite, but this appears to be simply a stringer running east and west. Little pay ore had been encountered in a long drift on the fourth level. The two lowest levels were not visited. It is reported that in the new workings at the bottom of the mine bornite and chalcocite have practically disappeared and pyrite carrying some gold is more abundant than it is above. Such a statement at once suggests secondary enrichment, but the writer believes that if this condition is general through the mine it is due to difference in original deposition resulting from unlike temperatures and pressures at different depths from the surface.

At the time of the writer's visit only the adit level was accessible. Here the average strike of the vein is about N. 42° W. and the dip 75°–80° NE. The tunnel follows a definite vein for about 500 feet; beyond this point the vein splits and becomes indefinite. The only

[11] Graton, L. C., op. cit., pp. 200–201.

stopes are within 400 feet of the portal and indicate three small ore bodies, each about 50 feet in drift length. Above the adit level there are old stopes, particularly near the junction of the Silver Bar and Twig veins, where both veins appear to have yielded ore. On the north side of the stream the Silver Bar vein has been developed to a considerable extent and exposed on at least two levels. The mine is now owned by the Socorro Mining & Milling Co. The production is said to have been about $1,700,000.[12]

ALBERTA MINE.

The Alberta mine lies near the crest of the ridge between Mineral and Silver creeks, about half a mile northwest of the Little Fanney. In this mine the Independence vein has been developed on the adit level for about 300 feet northwestward from its junction with the Ida May vein. The average strike is about N. 40° W. and the dip 60°–65° SW. The vein is well defined and over most of the distance developed exceeds 5 feet in width.

For 200 feet northwestward from the junction with the Ida May the drift is in good ore, said to have in places a tenor exceeding 70 ounces of silver to the ton. There has been no postmineral faulting and, although the depth below the surface is less than 300 feet, practically no oxidation. The ore consists of alternate bands of quartz with finely disseminated sulphides, chiefly argentite and calcite. In the low-grade material northwest of the ore shoot calcite predominates.

At the northwest end of the drift a 30-foot winze has been sunk and a short crosscut runs southwest from it. This cuts a 4-inch vein of chalcopyrite, partly oxidized to malachite and azurite.

JOHNSON MINE.

The Johnson mine has opened a small vein that crosses the head of Johnson Gulch with a westerly strike, dipping about 70° N. The mine was being prospected by the Socorro Mining & Milling Co. in 1916 but was idle in 1919. It has been developed by two inclined shafts on the vein, about 100 feet apart, connected by drifts on the first and third levels. The lowest level is about 300 feet below the collar of the eastern shaft. During a previous period of exploitation considerable stoping was done above an adit level east of the eastern shaft, and recent work has exposed small bodies of good ore in the lower levels. The vein is narrower than the more prominent veins, such as the Fanney, Maud S., and Last Chance, and in few places exceeds 3 feet in width. The cupriferous type of mineralization has occurred in places. The ore is almost completely oxidized.

[12] Scott, D. B., op. cit., p. 20.

LITTLE FANNEY MINE.

The Little Fanney mine is north of Silver Creek and has been one of the largest producers of the district. The production to date has been $4,869,000.[13] The mine was in operation at the time of the writer's visit in 1916 but was idle in 1919. The workings, which include those formerly known as the Little Charley mine, cover a vertical range of 1,500 feet and a length of 4,000 feet on the strike of the vein. (See Pl. XIX.) Ore has been exposed through a vertical distance of 1,200 feet, to the 1,100-foot level, and for about 2,700

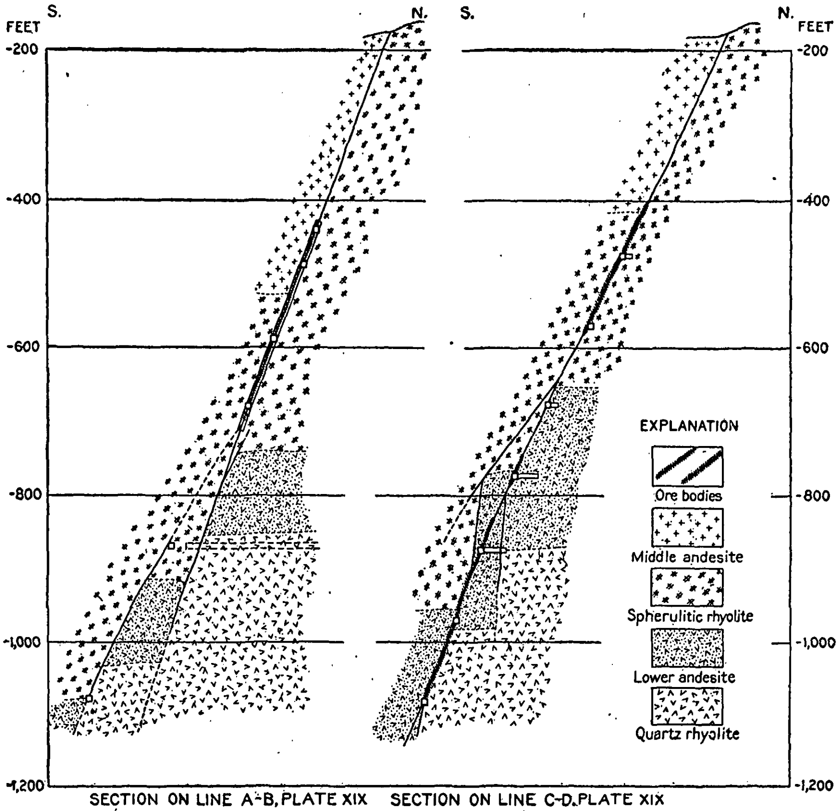


FIGURE 30.—Transverse sections across Fanney vein, Mogollon district, N. Mex., along lines A–B and C–D, Plate XIX.

feet along the strike. The strike over the greater part of the deposit is N. 74° W. and the dip about 70° S. In the eastern part, near the Queen vein, the strike is about northwest, and on the surface close to the Queen a north-northwesterly strike is observable. In the western part of the workings the vein appears to split into several branches. Minor splits in the vein are numerous and appear to exercise some degree of control over the position of the ore bodies. (See fig. 30.)

[13] Scott, D. B., op. cit., p. 15.

The ore is of the silver-rich type common to the district, copper minerals occurring only sparingly. The average ratio of gold to silver is 1 to 70.4 by weight. The usual grade of ore mined has a tenor of $10 to $12 a ton.

Two large and rather irregular ore bodies have been mined. The eastern of these appears to consist of two shoots—an upper flat shoot that bottoms at about the 300-foot level, which was inaccessible at the time of visit, and a lower irregular body between the 400-foot and 900-foot levels, embracing a maximum drift length of about 900 feet. The ore in this lower body consists entirely of sulphides, although traces of oxidation were observable in places down to the 1,100-foot level. Subsequent to the writer's visit a body of ore was found in the eastern part of the mine on the 1,100-foot level, supposedly at the junction of the Fanney and Ida May veins. The western ore body is divisible into two parallel eastward-pitching shoots, the eastern of which has been opened to the 1,000-foot level and the western to the 1,100-foot level. These shoots appear to be formed at the junction of the Fanney vein with intersecting fault veins (fig. 30). The ore in the western workings is for the most part completely oxidized and in places shows specks of free gold. The proportion of gold to silver is higher than in the unoxidized ore.

DEEP DOWN MINE.

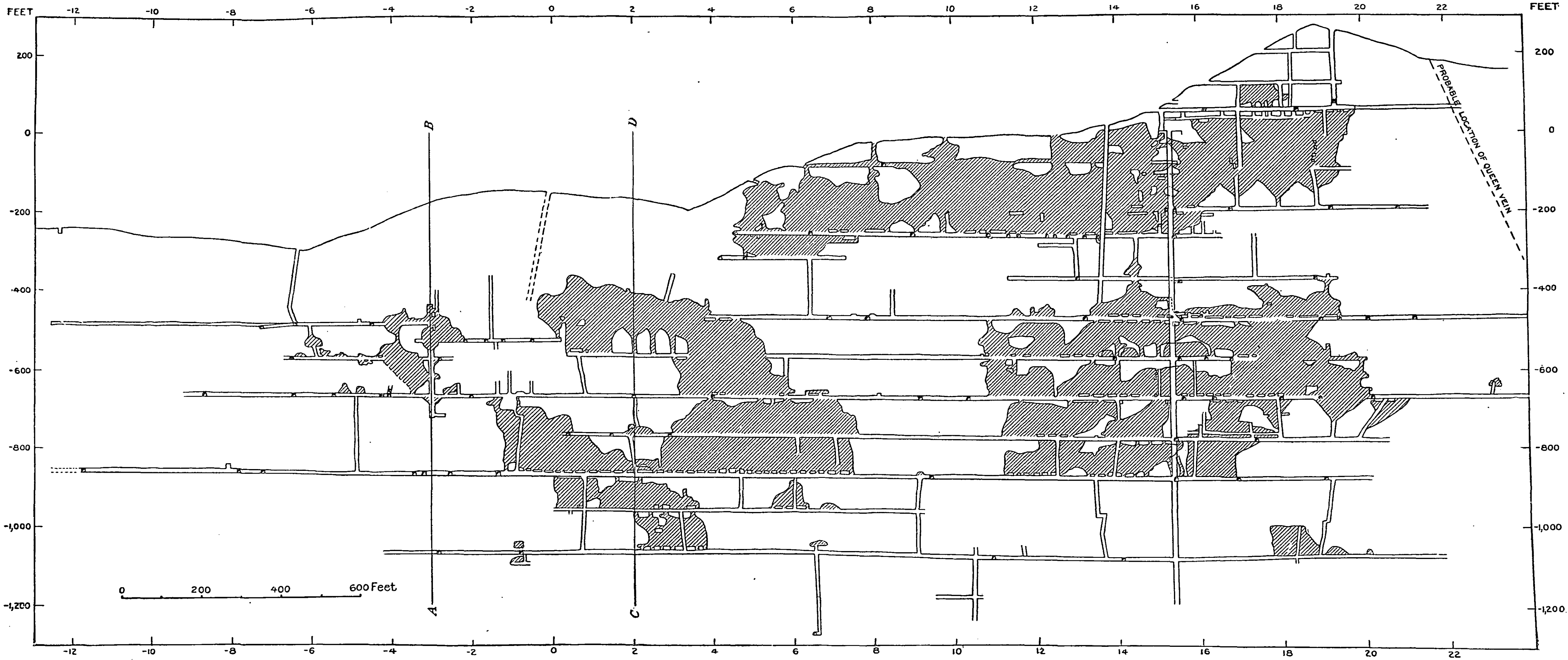
The Deep Down mine, southeast of the Maud S. mine, on the same vein but on the south side of Silver Creek, has not been in operation for many years. So far as known, all the ore produced (estimated by Graton as worth $75,000) came from stopes near the surface. Exploration in depth was apparently not profitable. The vein is similar in character to the others in the same region, but the width stoped does not appear to have anywhere exceeded 4 feet.

MAUD S. MINE.

The Maud S. mine is on the north side of Silver Creek about 2,000 feet west of the town of Mogollon and is owned by the Mogollon Mines Co. The mine is the oldest in this part of the district, but no work has been done for several years. The total production is said to be $800,000.[14]

The adit level is about 1,000 feet in length and shows a strike of N. 32° W. in the southeastern part and of N. 35° W. near the northwest end. The dip is about 65° NW. The principal ore body was in the southeastern part of the mine, where narrow stopes have been carried up to the surface, a distance of about 100 feet.

[14] Scott, D. B., op. cit., p. 18.



VERTICAL PROJECTION OF LITTLE FANNEY MINE, MOGOLLON DISTRICT, N. MEX.

Two shafts have been sunk on the vein. The old shaft, at the southeast end of the adit, reaches permanent water level at a vertical depth of about 200 feet, and the new shaft, at the northwest end, at a depth of 600 feet vertically, or 700 feet on the vein. Little work was done from the old shaft, although a small body of cupriferous ore was encountered above the 150-foot level. From the new shaft the vein was explored by drifts at the 400, 500, and 700 foot levels, but with the exception of a small body near the shaft on the 400-foot level no ore was found.

EUREKA PROSPECT.

The Eureka prospect lies just west of the area included in the geologic map, at the base of the cliff that forms the western edge of the range, between Silver and Mineral Creeks. The prospect was visited in 1916 but not in 1919.

As might be expected from the nearness of this prospect to the great fault on the edge of the range, postmineral faulting is here of considerable extent. The lower of the three tunnels starts in unconsolidated gravel and passes through the fault zone, which brings the gravel against the rhyolite.

From the work done at the time of the visit it could not be determined whether there were several veins present or whether a single vein had suffered complex postmineral faulting. The principal vein seems to strike about north and has an unusually flat dip—35° W. Intense postmineral movement is evident in the heavy gouge carrying particles of ore and in the crushed condition of the vein itself.

At the time of visit 95 tons of ore had been taken out. Of this 50 tons of high-grade ore assaying $98 in gold and silver to the ton was shipped direct to the smelter, and 45 tons assaying $22 to the ton was milled at the Deadwood and Socorro mills.

The ore is partly oxidized and carries a larger proportion of gold than is usual in the district. The gold-silver ratio is about 1 to 25, and free gold can be panned from samples of the best ore.

CLIFTON PROSPECT.

The Clifton prospect is on the Queen vein just north of Silver Creek. The vein, which is here from 20 to 30 feet wide and consists principally of white calcite, had in 1916 been developed by an adit for a distance of 500 feet. For about 100 feet there is along the hanging wall a shoot of ore containing sulphides, for the most part associated with amethystine quartz.

EBERLE MINE.

The Eberle mine, owned by Weatherhead & Cleaveland, has been developed by two tunnels. The mine was visited in 1916 but not in

1919. In the northern tunnel the Maud S. vein and a branch of the Queen vein have been prospected near their intersection. The southern tunnel follows the Queen vein to a point close to its intersection with the Maud S. Postmineral faulting has occurred along the footwall. The vein filling is largely calcite, but a small rich ore shoot consists chiefly of quartz carrying horn silver and a little native silver. A shaft near the portal of the southern tunnel has developed ore at a depth of 50 feet. Here argentite occurs in quartz closely associated with calcite and apparently also in the calcite as well.

DEADWOOD MINE.

The Deadwood mine was idle and inaccessible during both the writer's visits to the district. The workings lie beneath Deadwood Creek and receive the surface seepage, so that it is the only mine in the district that requires pumping. The vein, which is probably the southward extension of the Last Chance, has been explored for 500 feet below the collar of the shaft. The vein strikes nearly due north and is only a short distance from the Queen vein, which has been cut in the lower workings but not explored. Two ore bodies were encountered. The width of the vein is said to be 20 feet at its maximum and the width of the stopes from 8 to 13 feet. The ore is similar in character to the sulphide ore of the Last Chance. Between 1911 and 1914, 38,480 tons were mined, yielding 6,653 ounces of gold and 323,510 ounces of silver, or 0.173 ounce of gold and 8.40 ounces of silver to the ton. Up to the time of suspension of operations in 1915 the total production was 44,000 tons of ore, valued at $325,000.[15]

The mine has recently been taken under option by the Mogollon Mines Co., and the 300-foot level of the Last Chance has been extended to a point below the center of the north ore body.

LAST CHANCE MINE.

The Last Chance mine of the Mogollon Mines Co. is south of Silver Creek and just west of Deadwood Creek, about half a mile southwest of the town of Mogollon. The mine is the largest in the district, as the vein has been opened through a horizontal distance of nearly 4,000 feet and to a vertical depth of more than 1,400 feet below the highest point of the outcrop. The ore, as revealed up to the present time, shows a horizontal range equal to the total development and a vertical extent of 1,100 feet. The lowest level, 900 feet below the adit, showed no ore, although the new ore body encountered on the 500 and 700 foot levels in the west end of the mine gives promise

[15] Scott, D. B., op. cit., p. 15.

of greater extension in depth. The recorded production for the last 25 years has been about $7,500,000.[16]

The vein over the greater part of its length has an average strike of N. 69° W. and dips 60°–70° N. For the most part it follows a well-defined fault plane, but at one place it leaves the fault contact for a short distance. The fault contact itself shows several minor irregularities in the east end. Near the Queen vein the fissuring is more complex. The principal vein makes a sharp turn and for a short distance follows a course about N. 24° E. into the Deadwood mine. At this point a parallel vein about 30 feet to the west has yielded good ore over a short distance on the 300-foot level. On other levels branch veins connect the Last Chance and Queen veins.

The vein ranges from a mere fault contact, with slight mineralization, to 20 feet or more in width. The average width of stope is about 12 feet in the western part and 8 to 10 feet in the eastern part.

The ore bodies are large and irregular in outline. No definite pitch is observable, but there are numerous downward-projecting points. The lower boundaries of the ore shoots are as a rule indefinite, the ore passing gradually into material of similar nature below the limit of profitable exploitation. In their lateral extension there is usually one sharply defined border which can be correlated with a minor split in the vein. On the other end of such a body the boundary may be indefinite, the width of the vein remaining the same but the ore grading off into barren calcite. In the large ore body in the western part of the mine the vertical intersection of two veins forms the boundary of the ore body from the 150-foot sublevel to a point below the 500-foot level.

As can be seen from the projection (Pl. XX), the outcrop of the vein was ore bearing at only one point. Here the ore was largely oxidized, but the oxidation extended only to shallow depth. The ore bodies throughout the remainder of the mine, with one exception, contain sulphide ore almost exclusively. The principal sulphides are argentite and pyrite; copper minerals are of rare occurrence, although a mass of bornite was found at the east end of the 300-foot level. The new ore body in the extreme western part of the mine on the 500 and 700 foot levels is, however, almost completely oxidized and contains horn silver and native silver, and the large ore body just to the east, extending from the 150-foot to and below the 500-foot level, contains only sulphide ore. This peculiar condition appears to be due to postmineral faulting transverse to the vein, which is shown by a heavy streak of gouge that cuts the vein but does not penetrate the footwall. The oxidized ore contains a higher ratio of gold to silver than the average of the mine, which

[16] Scott, D. B., op. cit., p. 13.

is about 1 to 50, and several assays of material from the broken ground along the postmineral fracture showed a content of gold exceeding that of silver.

The Confidence mine, on the west, and the Deadwood, on the south, have recently been taken under option by the company. The workings of the three mines together on this vein aggregate about a mile and a half.

CONFIDENCE MINE.

The Confidence mine, west of the Last Chance and on the same vein, has been idle for many years. According to Graton[17] the workings extend to a depth of 1,030 feet. No ore, however, appears to have been mined below the 450-foot level. The largest ore body extended from the surface near the intersection of the Pacific vein to the 200-foot level, a vertical distance of about 500 feet. On the main level this body had a length of 800 feet. Smaller bodies that did not crop out were mined farther east. The ore was similar to that of the Last Chance but is reported to have been more largely oxidized. The production is said to have been about $1,200,000.

The 500 and 700 foot levels of the Last Chance mine are now being extended under the old eastern stopes of this mine, and the new body of oxidized ore discovered in these workings extends into the Confidence ground. (See Pl. XX.)

Oxidized ore has recently been mined on the surface at the intersection of the Pacific and Confidence veins.

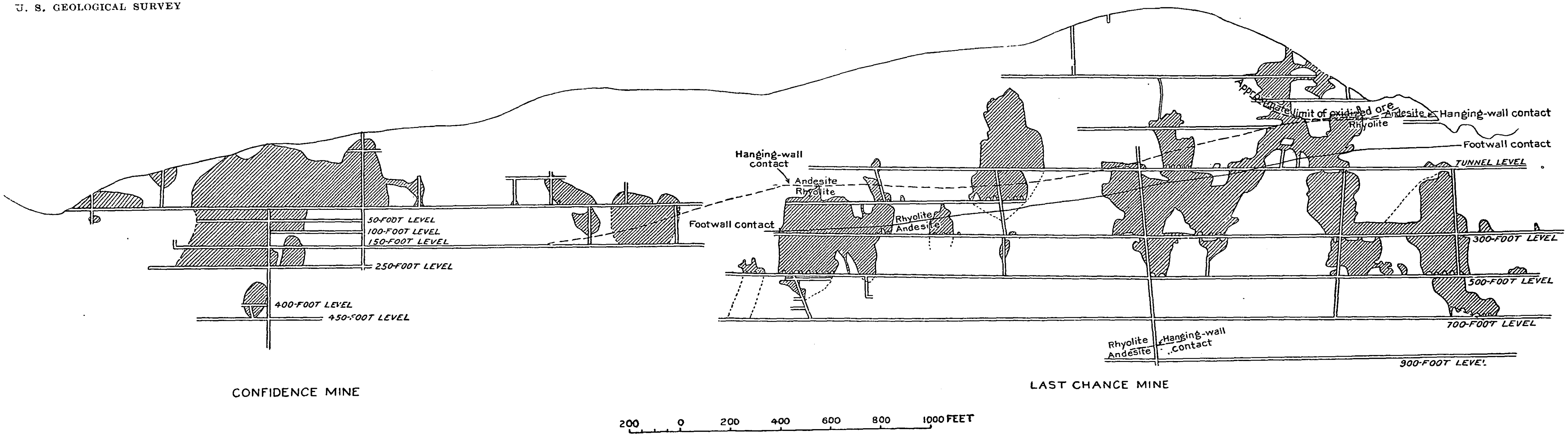
PACIFIC MINE.

The Pacific mine, which is on a northerly vein between the Confidence mine and Silver Creek, is one of the oldest mines of the district, but its production has been comparatively small. The mine was idle in 1919, but in 1916 it was being developed by the Socorro Mining & Milling Co., and the ore was carried to its mill at the Fanney mine by a cable tramway across Silver Creek. According to Scott[18] the production has amounted to about $200,000.

The vein strikes N. 6° W. and dips 70° E. It is well defined and can be followed from the Confidence vein to Silver Creek. Its width ranges from 1 to 15 feet. Its intersection with the Confidence vein is well exposed in the Confidence workings and shows contemporaneity of the vein filling.

The stopes are irregular, and no ore has been found below the third level, which is about 400 feet below the highest point of the outcrop. In contrast to the ore of other mines of the district the Pacific ore is oxidized and very irregular in tenor. The good ore is

[17] Graton, L. C., op. cit., p. 199.
[18] Scott, D. B., op. cit., p. 19.



VERTICAL PROJECTION OF LAST CHANCE AND CONFIDENCE MINES, MOGOLLON DISTRICT, N. MEX.

spotty in occurrence and the ore bodies are irregular. The highest-grade ore contains horn silver, a little native silver, and rare specks of native gold.

Postmineral movement has been more prominent here than in other mines of the district, and a streak of gouge in places a foot wide follows the hanging wall. The gouge consists of a sticky red mud containing fragments of quartz and wall rock.

SOUTH ALPINE PROSPECT.

The South Alpine claim, on the northward extension of the Pacific vein, has produced ore from surface stopes near the top of the south wall of Silver Creek canyon. Recently a new ore body has been discovered farther north, about 100 feet above Silver Creek. The prominent post-mineral faulting of the Pacific vein is lacking here, and a well-defined vein with tight walls follows the earlier fault contact.

The ore shows a large proportion of copper minerals, principally malachite and cuprite. In places pyritous ore with a high silver content is found. In this ore small plates of native silver occur close to the pyrite crystals or in threadlike veinlets associated with iron oxide. Horn silver is found in vugs and fractures in the quartz. Free gold occurs in small amount.

IRON CROSS PROSPECT.

The Iron Cross prospect lies just south of the area included in the detailed map (Pl. XV) near the top of the north wall of Whitewood Canyon. The ground is developed by two small tunnels, about 100 feet vertically apart, and a shaft from the upper tunnel reaching nearly to the lower. The vein appears to be the southern extension of the Queen vein.

Faulting is complex and, at least in part, is postmineral. The vein is accompanied by a thick seam of gouge containing crushed fragments of vein matter.

The best ore is said to have come from the shaft, and 32 tons with an assay value of $15 to $20 a ton has been mined. The ore shows a much brecciated chalcedonic to fine-grained quartz, with the fragments cemented by red iron oxide. The fragments of chalcedonic quartz are in places cut by veinlets of drusy quartz. Rare specks of pyrite are visible, usually close to small fragments of altered wall rock, included in the vein. Another vein, as yet undeveloped, strikes about west along the base of a steep rhyolite cliff. Along the outcrop of this vein are masses of psilomelane together with brecciated rhyolite cemented by quartz.

SUMMARY.

The rocks of the Mogollon district are nearly all lavas or sedimentary rocks composed of materials derived from lavas. Flows of rhyolite and andesite, together with sedimentary and pyroclastic rocks, had reached a total thickness of several thousand feet when faulting of considerable magnitude took place and the region was broken up into irregular blocks bounded by normal faults.

The faulting was closely followed by the introduction of mineral-bearing solutions, which followed channels determined by the previous faulting, so that practically all the faults are the sites of veins.

The faulting and the introduction of the mineral veins marked the end of the period of volcanism, and except for a few basalt dikes no postmineral igneous rocks are found in the area. The faulted region suffered extensive erosion, and later a considerable thickness of gravel was deposited over part of it.

In comparatively recent geologic time renewed faulting took place along what is now the front of the range. The disturbance was confined principally to the great fault that bounds the range, but some minor movements took place along the faults that had been formed in the earlier period.

The ores of the district are valuable mainly for silver. Argentite, pyrite, bornite, chalcopyrite, and tetrahedrite, together with small amounts of horn silver and native silver, are the principal ore minerals. The gangue consists chiefly of quartz, calcite, and a little fluorite. The veins are large and well defined.

The ores are principally sulphides and give evidence of being in part due to enrichment, although the relative importance of secondary processes has not yet been fully determined.

The productive portion of the district covers only a comparatively small area. Elsewhere the veins, though well defined, are mostly barren. The cause of this extreme localization is believed to lie in differences in the distance from the original surface at the time of deposition. In those areas which have suffered the least relative depression through faulting the ores have been largely removed by erosion. On the other hand, in those areas of greatest relative depression erosion has not yet reached the zone of ore deposition.