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GEOLOGY OF THE SANTA RITA MINING AREA NEW MEXICO

BY

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GEOLOGY OF THE SANTA RITA MINING AREA, NEW MEXICO

By A. C. Spencer and Sidney Paige

ABSTRACT

The Santa Rita mining area (pl. 1), covering 35 square miles of semiarid mountainous land, lies within the Silver City 30-minute quadrangle, Grant County, N. Mex., and includes the most productive part of the Central or Hanover mining district. Ore was produced in this district as early as 1804 and production continued intermittently for a century before the developments were undertaken that led to large-scale copper mining, which began in 1912. The output of zinc, lead, and iron increased markedly about the same time.

The sedimentary rocks of the district include the Bliss sandstone (Upper Cambrian), El Paso, and Montoya limestones (Ordovician), Fusselman limestone (Silurian), Percha shale (Devonian), Lake Valley limestone (Mississippian), Magdalena group (Oswaldo and Syrena formations, Pennsylvanian), Abo redbeds (Permian), and Beartooth quartzite and Colorado shale (Cretaceous). Intense metamorphism has profoundly changed the appearance of the formations, particularly the limestones and the Abo redbeds, throughout much of the district, and for this reason it has been impracticable to map the Montoya and Fusselman limestones separately. Unconformities are recognized at the tops of the El Paso, Fusselman, and Abo formations. The thicknesses, especially of the lower formations, have been considerably reduced by the squeezing that accompanied the granodiorite intrusion in the vicinity of Hanover.

Igneous activity took place in Cretaceous and Tertiary time. The igneous rocks of known Cretaceous age include volcanic breccia intercalated in the upper part of the Colorado shale; the late Cretaceous or early Tertiary rocks include later stocks, sills, dikes, one great laccolith of quartz diorite porphyry, and still later intrusive stocks of granodiorite. Two of these stocks, the Santa Rita and Hanover-Fierro, are accompanied by the principal ore deposits of the district. The Tertiary formations include basal tuffs, breccia, and gravel deposited on a maturely eroded surface, alternating flows of rhyolite and andesite, and dikes and small stocks of quartz latite.

The principal structural features include folds of Cretaceous age and faults that were formed in late Cretaceous, Tertiary, and Quaternary time. The principal fold, called the Fort Bayard arch, extends southwestward across the area and is modified by a few local transverse folds, some of which were clearly formed at the time of the granodiorite intrusions. Although some faulting may have preceded these intrusions, the earliest clearly recognized faults were formed a little later, and many of them served as conduits for ore-forming solutions. Tertiary faults displace the lavas that rest unconformably on the Cretaceous rocks, and a few faults in or near the area displace alluvial deposits

that are presumably of early Quaternary age. Renewed movement along the older faults took place during the later periods of faulting.

Metamorphism is pronounced in fractured ground within and adjacent to the marginal parts of the granodiorite stocks. The effects of metamophism are reflected in the recrystallization of limestones, the development of silicates in limestone and shale, the replacement of limestone by ores of iron and zinc, the sericitization and silicification of shale and sandstone, and the widespread sericitization of quartz diorite and granodiorite. Alteration that followed intrusion of the Tertiary stocks was mainly expressed by alunite.

Prolonged erosion followed metamorphism and ore deposition and was accompanied by some enrichment of the deposits before they were covered by Tertiary rocks. After erosion had removed these rocks from the mineralized areas enrichment was resumed.

The principal ore deposits include the contact-metamorphic depostis of magnetite; sulphide deposits, mainly of zinc blende, that have replaced limestone mainly in the vicinity of Hanover and Fierro; and the great deposit of disseminated copper sulphide that has impregnated granodiorite, quartz diorite, and adjacent siliceous sedimentary rocks in the vicinity of Santa Rita. The value of the copper ore is due almost entirely to supergene enrichment. Besides these large ore bodies there are many veins closely related to the replacement sulphide bodies in origin. Few of these veins have been profitably worked, but the Groundhog vein is a notable exception.

INTRODUCTION

FIELD WORK AND ACKNOWLEDGMENTS

Investigation of the Santa Rita area was begun by A. C. Spencer late in September 1914 and continued through January 1915. During this time he was assisted for 3 weeks by J. Fred Hunter and for 7 weeks by Sidney Paige, who had previously mapped the Silver City 30-minute quadrangle, which includes the Santa Rita area. Diversion of the Geological Survey's activities during the World War partly accounted for suspension of work on the report, and it was not resumed until 1927, when Mr. Spencer was in the district from April to November studying new developments and mapping parts of the area in greater detail. This work also called for some revision of the topographic base map. In the spring of 1932 Messrs. Spencer and Paige revisited the district shortly before completion of the report.

During 1927 Mr. M. J. Ballmer, of the Chino Copper Co., was of great assistance in the field and in the preparation of maps and other data, and Mr. R. E. Landon served as Mr. Spencer's assistant for a few weeks. In 1932 Mr. S. G. Lasky, of the United States Geological Survey, who had been studying the adjoining part of the central district, supplied data on the southwest corner of the area.

It is a pleasure to acknowledge the receipt of many courtesies from the mining men of the district. To the late Mr. J. M. Sully, local general manager of the Chino Copper Co., the writers are especially indebted for cooperation in affording every facility for the study

of the mines at Santa Rita and in making available all the records of the company relating to churn-drill explorations, as well as a report made for the company by E. H. Wells in 1923. Mr. Wells, present director of the New Mexico Bureau of Mines and Geology, lost no opportunity to aid the writers in many different ways.

GEOGRAPHIC POSITION

The Santa Rita area is in Grant County, N. Mex., between meridians 108°3′ and 108°8′ west longitude and parallels 32°46′ and 32°52′ north latitude. (See pl. 1.) It measures about 4.8 by 6.8 miles and has an area of slightly less than 33 square miles. It lies within the Silver City 30-minute quadrangle and in the territory known officially as the "central mining district."

The mines at Santa Rita are about 12 miles east of Silver City, the administrative seat of Grant County, and 50 miles northwest of Deming, in Luna County. The region is served by branch lines of the Atchison, Topeka & Santa Fe Railway, one reaching the iron and zinc mines at Fierro and Hanover and another the copper mines at Santa Rita.

TOPOGRAPHY

South of the great upland of Arizona and New Mexico, the Colorado Plateau, there is a mountainous region, with ranges rising, in part, from broad desert valleys. It has certain topographic and geologic features that resemble those of the Basin Range province of Nevada and Arizona. One of these relatively low and extensive desert valleys extends west and northwest from Deming, envelops several minor groups of mountains, and penetrates the more consistently mountainous region that forms the Continental Divide southwest and northeast from Silver City. Between the east edge of this desert and the upper valley of the Mimbres River there is a belt 15 miles long of irregularly disposed mountains and hills, within which the Santa Rita area is situated.

Streams of the Santa Rita area drain almost entirely southward into this desert valley, partly by way of Cameron Creek through the Fort Bayard Military Reservation but mainly through Whitewater Creek. Tributaries that join Whitewater Creek within the quadrangle are Gold Gulch, Hanover Creek, and Santa Rita Creek; the basin of Gold Gulch lies wholly within the area, and those of Hanover and Santa Rita Creeks extend only a short distance beyond the boundaries. The area is not well watered by running streams, but each of the creeks named has at least a small discharge throughout the year. During the summer wet season the streams fluctuate greatly in volume and are subject to floods after occasional violent rains.

Altitudes range from 5,820 feet on Whitewater Creek near the southwest corner of the area to 7,700 feet near the southeast corner and to 8,060 feet at a point 1½ miles east of the northwest corner. Along the southern margin of the area a deeply incised but bold escarpment faces north, marking the eroded edges of nearly flat-lying lava beds 800 feet or more in thickness. Picturesque serrated ridges above an irregular and sinuous line of cliffs dominate the generally rolling country drained by the upper Whitewater Valley, Santa Rita Creek, the lower part of Hanover Creek, and the gulches in the western part of the area that drain to Cameron Creek.

In the north-central part of the area a series of ridges and peaks, ranging in altitude from 6,800 to more than 7,500 feet, enclose an oval flaring valley that constitutes the upper basin of Hanover Creek. Within this wider valley is a more constricted basin walled by resistant metamorphosed sedimentary rocks and floored by the rock of the Hanover intrusive stock, which, because it crumbles readily under the action of the weather, has been deeply eroded. Hermosa and Hanover Mountains, situated on the basin rim, rise to altitudes exceeding 7,500 feet, or about 800 feet above Hanover Creek, and are the highest points in the area outside of the lava mountains. The north edge of the area includes part of the bold southward-facing front of forest-clad, rugged lava ranges that occupy an extensive region to the north, similar geologically to the mountains south of Santa Rita.

CLIMATE AND VEGETATION

The climate of Grant County is semiarid, though by reason of a considerable range in altitude there are great local differences in the mean annual temperature and rainfall and corresponding marked differences in the character and density of vegetation. A summary of meteorologic observations[1] taken at Fort Bayard, 5 miles west of Santa Rita, for the years 1895 to 1903, shows a mean annual temperature of 56° F., with an absolute range from 1° to 103° F., and a mean annual precipitation of 14 inches. At Santa Rita the annual temperature is probably about the same as at Fort Bayard, but records kept by the Chino Copper Co. since 1911 indicate a somewhat greater precipitation, that for the years 1911 to 1914 ranging from 16.77 to 24.65 inches. The hottest weather is usually experienced in June and July, and the greatest rainfall usually comes during the summer in the form of daily afternoon showers and occasional heavy downpours.

The mountainous country north of the Santa Rita area, with altitudes between 7,000 and 8,000 feet, supports a rather dense forest

[1] Henry, A. J., Climatology of the United States: U. S. Weather Bur. Bull. Q, p. 897, 1906.

growth, including conifers valuable for timber, whereas in lower country like the Santa Rita area such trees as the white pine are rather unusual, and juniper and piñon predominate. Throughout the region tributary to the upper basin of Whitewater Creek, these trees, together with a variety of live oak, also predominate, though ash and black walnut occur along some of the streams. These trees all grow to considerable size but are very unevenly and in general sparsely distributed, so that the country has a parklike rather than a forested aspect.

Among the larger shrubs mountain mahogany is of common occurrence, and among the smaller woody plants the thorny cat's claw. Very striking to one unfamiliar with the southwestern region are several large varieties of cactus, the maguey or century plant, two or more varieties of yucca, and the soap plant or saponilla, of somewhat similar appearance. The herbaceous flora comprises many flowering plants and a considerable variety of grasses, the latter mainly low species such as characterize the grazing lands of the high plains in Colorado and western Texas.

HISTORICAL DATA

HISTORY OF MINING

Data are not at hand for more than a meager sketch of the history of mining in the Santa Rita area. First interest naturally centers about the early history and development of the Santa Rita copper mines, of which accounts are given by Raymond,[2] Jones,[3] and Sully.[4] These accounts have furnished most of the following data.

The Central mining district, sometimes called the Hanover district, appears to have been organized about 1860, or at the same time as the Pinos Altos district. However, the Hanover mine, near the present town of Fierro, was producing copper as early as 1858, and the copper at Santa Rita had then been known for many years.

Perhaps no more than traditional value attaches to the statement, but it is related that about the year 1800 the croppings near which the Romero shaft was afterward opened were shown to Lt. Col. José Manuel Corrasco, an officer in charge of the Spanish military posts in this general district, by a friendly Apache chief. Colonel Corrasco interested Don Manuel Francisco Elguea,[5] of Chihuahua, Mexico, and a concession under the law applicable to New Spain and its provinces was obtained. Elguea, who was a subdelegate to the Spanish court,

[2] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1869, pp. 402–404, 1870.

[3] Jones, F. A., New Mexico mines and minerals, pp. 34–43, 1904.

[4] Sully, J. M., private report printed in 1909.

[5] In Raymond's account the name is given as "De Alguea", and another variant given by Jones is "Lagera."

made a contract with the Government to furnish the vice royalty of New Spain with copper for coinage, the Government agreeing to take the whole product of the mines, and in 1804 he purchased the concession and began production. Though the indicated position is not correct, the Santa Rita mines were doubtless referred to in the statement made by Pike [6] in reporting on his expedition of 1807: "There are no mines known in the province, except one of copper situated in a mountain on the west side of the Rio del Norte, in latitude 34°. It is worked and produces 20,000 mule loads of copper annually."

In charge of the mines during the first years of operation was Juan Onis (or Ori), who, after the death of Elguea in 1809, worked the property under arrangement with his widow. Rough metallurgical works are said to have been provided, and the metal produced was transported by pack trains under military convoy to Chihuahua and thence to Mexico City.

A triangular adobe fort with massive towers at the corners was erected as a needed protection against hostile Apaches. The towers were round and had walls more than 3 feet thick. Two of them were standing as late as 1909, and one has been roofed over and preserved as an interesting historical monument.

According to Jones, Onis was succeeded as lessee by two brothers named Pattie, and about the year 1822 the property was sold by the widow of Elguea. From 1826 to 1834 it was held and worked by Robert McKnight. Next the mines passed into the possession of one Siqueiros, who operated until the later part of the decade 1850–60, though under difficulties due to hostilities on the part of the Indians.

From 1860 to 1870 the property was held by Sweet & Coste and their associates and appears to have been worked, except for a period after 1862, when the territory was invaded by Confederate forces under General Sibley, the mine works were destroyed and a large amount of copper was confiscated. In 1869 a small blast furnace was in operation, and production for 8 months of the year was reported at 12,600 pounds.

The Hanover mine had been opened prior to the Sibley invasion and is said to have produced between 1858 and 1861 nearly 1,000,000 pounds of copper. The ore was treated in a blast furnace and refined in a reverberatory furnace at a stated cost of 10 cents a pound.[7] The product was hauled by way of Mesilla to Port Lavaca, Tex., and transported thence by schooner to New York, making the total cost 16¼ cents a pound; the normal price for copper at that time was 23 cents.

[6] Pike, Z. M., Account of expeditions to the sources of the Mississippi, and a tour through the interior parks of New Spain, appendix to pt. 3, p. 5, 1810.

[7] Raymond, R. W., op. cit., p. 402.

After the Civil War efforts were made by different persons to obtain title to the Santa Rita mines under the mining laws of the United States. All applications for patent were denied, however, the final decision having been reached by the Secretary of the Interior in 1873, with the ruling that the claimants had no right to the mine, which had been known to the Department for more than half a century as belonging to the Elguea estate.

In the same year that this decision was rendered, M. B. Hayes and associates succeeded in obtaining title from the heirs of Elguea, who were sought out in various parts of Mexico and Europe. Afterward the lands were located, and eventually patents were obtained from the United States Government.

In 1875 the Chino and Yosemite mines, at Santa Rita, and the San Jose mine, 2 miles west, were mentioned by Raymond. About 1881 the Santa Rita mines were purchased by J. Parker Whitney, whose name is associated with copper mining in the Lake Superior district, and in 1882 the plant included a stamp mill equipped with jigs, a water-jacketed blast furnace, and a reverberatory refining furnace.[8] Under the ownership of Mr. Whitney the property was worked mainly by tributers. In 1897 a lease and bond was given to the Hearst estate, and development work, under the management of B. B. Thayer, resulted in the discovery of a large deposit of sulphide ore in the southwestern part of the Santa Rita Basin. In 1899 the property was sold to the Santa Rita Mining Co., organized by men who were or had been connected with the Amalgamated Copper Co The policy of leasing was continued, and ore carrying about 10 per-cent of copper was purchased from lessees by the company.[9] Material from old dumps was treated in a 90-ton concentrator, and an experimental leaching plant was installed.

Exploration work carried on about 1906 by the Santa Rita Mining Co. did not lead to the discovery of hoped-for ore bodies of high grade, and in 1909 the property was sold to the Chino Copper Co.

The deposits of iron ore in the vicinity of Fierro had long been regarded as an important asset, the realization of which began with the building of the Hanover branch of the Silver City & Northern Railroad in 1891. Shipments to the Pueblo furnaces of the Colorado Fuel & Iron Co. began in that year, and each year since more than 100,000 tons of iron ore has been mined.

Between 1891 and 1899, when the Santa Rita branch railroad was built several copper properties in the Hanover section were explored, operations were carried on at Copper Flat, and the mining of oxidized zinc ores began. Essentially self-fluxing copper-iron ores were developed, and smelters were erected at the Anson S. mine and

[8] Min. and Sci. Press, vol. 45, p. 273, 1882.
[9] Mineral Industry, vol. 9, p. 195, 1901.

at Copper Flat. Shipments of ore carrying excess iron had been previously made from the Iron Head mine, and in 1898 and 1899 a considerable tonnage was shipped to smelters at Deming and Silver City. At about this time the Phelps Dodge Co. became interested in the area and took over several properties, including the Modoc, Hanover, and Emma. In the Modoc mine a reserve of fluxing ore was developed but not mined. The Hanover and Emma mines were for several years producers of copper ore suitable for direct smelting. The Emma mine was worked by lessees in 1908 and by the Copper Queen Consolidated Mining Co. in 1910.

In 1903 a discovery of rich gold ore was made on the Pactolus claim, in Gold Gulch, but the deposit first found was soon worked out and, as others were not discovered the resulting excitement was only short-lived. The Hermosa Copper Co., affiliated with the General Electric Co., was organized in 1905. This company purchased or took options on several slightly developed properties of apparent promise and began a campaign of exploration on scattered claims near Hanover and on a compact group of claims adjoining the lands of the Santa Rita Mining Co. on the west. A concentrator for testing purposes was built on Hanover Creek 1½ miles below Hanover, shafts were sunk at eight points, and within 2 years nearly 3 miles of underground workings were opened. It is reported [10] that as a result of this work only 25,000 tons of 3 percent copper ore was blocked out. In 1918 the lands of this company were transferred to the Chino Copper Co.

In 1906 J. M. Sully, then engineer and assistant superintendent for the Hermosa Copper Co., was detailed to study the copper deposits of the Santa Rita Basin, with a view to determining the possibility of developing them by methods that were then coming into prominence through the operations of the Utah Copper Co. at Bingham, Utah. Systematic sampling of accessible workings and 110 dumps was begun, and during this first investigation 2,876 samples weighing from 300 to 500 pounds were taken and submitted to assay. It is understood that the report made by Mr. Sully to his company recommended negotiations for the purchase of the property, but any move that may have been made in this direction is not known to the public. In 1908 Mr. Sully carried out a still more extensive sampling of the mine workings and prepared a report for the owners indicating the practicability of developing the property on an extensive scale as a low-grade mine. Early in 1909 the Sully report was privately printed and circulated in connection with a plan devised by Thomas W. Lawson for financ-

[10] Copper Handbook, vol. 8, p. 785, 1908.

ing the Santa Rita Mining Co. Instead of pushing the Lawson plan, the owners sold the property to the Chino Copper Co., organized in May 1909.

Exploration by means of churn drills, which had been begun in 1908, was vigorously pushed by the new company, and by December 1912 the amount of copper ore developed was estimated at 90,000,000 tons, having an average grade of 1.8 percent. Steam-shovel operations were begun in September 1910, and before the end of that year four shovels were engaged in stripping the ore bodies. The construction of the concentrating mill at Hurley was begun in October 1910. A year later the first one of five sections was started, and by the middle of 1912 ore was being mined and milled at the rate of more than 1,000,000 tons a year. Developments since then are reflected in the table of production on page 10.

PRODUCTION

According to Thorne,[11] "no recorded figures are available for the years previous to 1845, but from the various works in which the Santa Rita del Cobre grant is mentioned, it is estimated that previous to 1845 there were produced not less than 41,000,000 pounds of copper." Figures on smelter production in New Mexico as a whole from 1845 to 1910 were assembled from the annual volumes of Mineral Resources, by Butler,[12] who stated that this production was principally from the districts in Grant County; but as Grant County then included the Burro Mountains and Lordsburg districts, whose combined production in some years exceeded that of the Central district, a close estimate of the Central district's copper production during that period appears impossible. Comparison of the figures of smelter production for New Mexico as a whole with those of mine production in the Central district during 1904–10 shows that the district contributed from about three-sevenths to about three-fifths of the total. Since 1904 figures on production of metals except iron in the Central district have been published in Mineral Resources, and those for 1904–30 are quoted below.[13] According to this table the Chino Copper Co. became a large producer of copper in 1912, and production of zinc and lead, mainly from mines around Hanover, also increased greatly. Production was interrupted during the short industrial depression of 1921 but resumed its advance, with some fluctuations, until the great depression

[11] Thorne, H. A., Mining practice at the Chino mines, Nevada Consolidated Copper Co., Santa Rita, N. Mex.: U. S. Bur. Mines Inf. Circ. 6412, p. 4, 1931.

[12] Butler, B. S., U. S. Geol. Survey Mineral Resources, 1910, pt. 1, p. 204, 1911.

[13] Henderson, C. W., Gold, silver, copper, lead, and zinc in New Mexico: U. S. Bur. Mines Mineral Resources, 1929, pt. 1, p. 747, 1931; idem, 1930, pt. 1, p. 805, 1932.

that began in the fall of 1929. In that year copper production reached its maximum, but production of lead and zinc made further increases in 1930.

Mine production of gold, silver, copper, lead, and zinc in Central district, Grant County, N. Mex., 1904–32, in terms of recovered metals

Year	Ore	Gold	Silver	Copper	Lead	Zinc	Total value
	Short tons		*Fine ounces*	*Pounds*	*Pounds*	*Pounds*	
1904	21, 048	$5, 582	282	3, 264, 208	11, 977	----------	$424, 080
1905	20, 252	----------	8	3, 179, 206	----------	96, 424	501, 650
1906	39, 155	4	2, 524	3, 075, 001	235, 070	99, 656	614, 673
1907	57, 079	5, 659	36, 813	4, 994, 575	855, 358	73, 729	1, 078, 555
1908	41, 852	777	296	3, 994, 502	29, 122	251, 070	541, 231
1909	41, 456	816	1, 380	3, 348, 808	23, 256	203, 278	448, 856
1910	37, 008	----------	404	2, 679, 630	155	1, 285, 500	409, 955
1911	45, 584	104	8, 673	1, 413, 189	605, 978	290, 122	225, 156
1912	1, 136, 290	998	29, 586	29, 512, 812	2, 172, 676	2, 205, 824	5, 138, 779
1913	1, 948, 471	9, 697	12, 500	51, 695, 656	331, 440	2, 187, 266	8, 167, 144
1914	1, 934, 020	102, 971	42, 971	55, 222, 874	365, 079	3, 669, 513	7, 672, 759
1915	2, 395, 795	102, 379	73, 267	66, 581, 366	1, 542, 234	5, 628, 870	12, 561, 729
1916	3, 134, 791	133, 962	116, 953	74, 228, 606	2, 122, 797	7, 278, 575	19, 592, 956
1917	3, 668, 289	138, 873	121, 386	82, 200, 421	2, 250, 337	7, 398, 853	23, 627, 822
1918	3, 908, 816	128, 577	111, 175	77, 547, 300	2, 857, 887	8, 826, 967	20, 400, 099
1919	1, 789, 083	57, 280	34, 508	40, 358, 634	1, 283, 642	4, 299, 658	7, 984, 543
1920	1, 882, 172	68, 962	26, 190	44, 400, 088	925, 513	6, 134, 593	8, 838, 068
1921	362, 331	10, 439	9, 688	9, 138, 442	4, 422	95, 000	1, 203, 935
1922	1, 426, 783	24, 537	11, 326	28, 408, 184	352, 640	1, 333, 440	3, 966, 369
1923	2, 885, 711	68, 108	29, 264	54, 374, 770	1, 311, 141	13, 017, 000	9, 062, 131
1924	2, 859, 688	71, 121	38, 200	66, 824, 015	1, 183, 626	16, 921, 000	10, 045, 216
1925	3, 159, 167	97, 299	76, 547	68, 812, 280	2, 363, 260	15, 033, 000	11, 269, 879
1926	3, 633, 821	109, 335	86, 963	75, 219, 200	2, 611, 100	14, 327, 000	11, 977, 701
1927	3, 087, 823	98, 963	85, 963	66, 971, 008	1, 907, 476	10, 076, 000	9, 685, 941
1928	3, 723, 753	113, 507	143, 993	80, 238, 820	2, 359, 155	15, 089, 000	12, 809, 393
1929	4, 135, 864	131, 631	374, 398	87, 445, 648	7, 532, 318	22, 448, 000	17, 677, 723
1930	2, 667, 267	77, 110	407, 608	57, 243, 200	7, 872, 000	30, 638, 000	9, 539, 879
1931	2, 714, 360	72, 708	435, 338	56, 317, 175	6, 840, 600	14, 099, 000	6, 112, 683
1932	1, 231, 876	31, 108	474, 479	26, 512, 900	7, 041, 400	10, 241, 000	2, 353, 696
	53, 989, 605	1, 662, 507	2, 792, 683	1, 225, 202, 518	56, 991, 659	213, 247, 338	223, 932, 601

The production of iron ore, according to information supplied by the United States Bureau of Mines, includes 44,500 long tons mined by the Southwestern Coal & Iron Co. for the period 1891–96 and 4,685,301 long tons, most of it mined by the Hanover Bessemer Iron Association and its successor, the Hanover Bessemer Iron & Copper Co., for the period 1896–1931.

LITERATURE

In spite of the long period of mining at Santa Rita and the present industrial importance of the district, there have been very few published articles dealing with its geology or describing its ore deposits. The following list is probably essentially complete as regards papers of permanent value, and certain titles have been included merely because of their historical interest.

Owen, R. E., and Cox, E. T., Report on the mines of New Mexico, Washington, published by John S. Watts, Territorial Delegate, 1865. Notes on the occurrence of iron ore near Hanover and on the copper mines at Hanover, Santa Rita, and San Jose.

Taylor, J. W., Report on the mineral resources of the United States east of the Rocky Mountains, Washington, 1868. On page 6 the Hanover and Santa Rita mines are described.

Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1869 to 1875. The reports for 1869, 1873, and 1875 contain historical and geologic data relating to the Santa Rita and neighboring mines.

Blake, W. P., Zinc-ore deposits of southwestern New Mexico: Am. Inst. Min. Eng. Trans., vol. 24, pp. 187–195, 1894. Notes on the occurrence and mineralogy of the zinc deposits near Hanover.

Birkinbine, John, The occurrence of iron ores in the Rocky Mountains region: U. S. Geol. Survey 18th Ann. Rept. pt. 5, pp. 45–49, 1897. Includes a brief description of iron-ore deposits near Hanover.

Emmons, S. F., The secondary enrichment of ore deposits: Am. Inst. Min. Eng. Trans., vol. 30, pp. 43–109, 1901. Brief account of the occurrence of copper ores at Santa Rita.

Frost, Max, Mines and minerals of New Mexico, Santa Fe, N. Mex., 1901. Notes relating to the Hanover and Santa Rita mines.

Jones, F. A., Mines and minerals of New Mexico (World's Fair edition), Santa Fe, N. Mex., 1904. Includes geologic notes and historical review of mining at Hanover and Santa Rita.

Paige, Sidney, The Hanover iron-ore deposits, New Mexico: U. S. Geol. Survey Bull. 380, pp. 199–214, 1909. Describes the general geology of the Hanover Basin, the principal features of metamorphism adjacent to the Hanover stock, and the occurrence of the iron ores.

Sully, J. M., Report on the property of the Santa Rita Mining Co., Boston, 1909. Contains a brief history of mining and notes on the geology of the Santa Rita Basin. The ground developed or partly developed at the time is credited with 12,000,000 tons of ore averaging 2.4 per cent copper.

Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, 1910. Describes the general and economic geology of the mining districts of Grant County, N. Mex.

Dinsmore, C. A., The Chino Copper property, New Mexico: Min. World, vol. 33, pp. 357–359, 1910. A general description of the property in the development stage.

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STRATIGRAPHY

PALEOZOIC FORMATIONS

The distribution of the sedimentary formations in and around the Santa Rita area is shown on plate 1, and their succession and thickness, where not profoundly changed by deformation, are shown in plate 3.

BLISS SANDSTONE (CAMBRIAN)

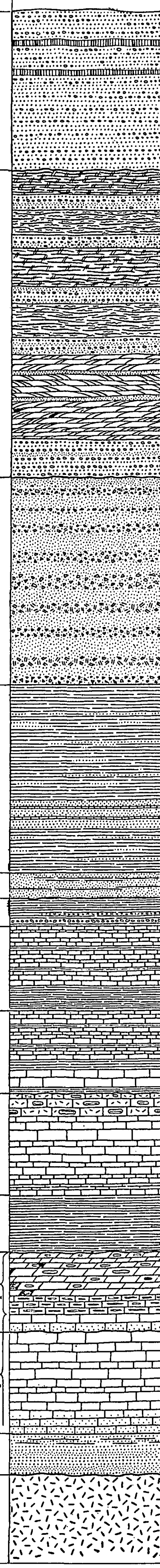
Throughout southern New Mexico the oldest formation of the Paleozoic succession is the Upper Cambrian Bliss sandstone, the type locality of which is in the Franklin Mountains, about 100 miles southeast of Santa Rita. In the Silver City region characteristic exposures are to be found on the west slope of the Continental Divide, where the normal thickness is about 180 feet, and along the west side of Mimbres Valley, where observations show thicknesses ranging from 125 to 165 feet. Typical sections show ledges of gray, green, and red or brown sandstone and quartzite, from 4 to 20 feet thick, separated by thin beds of limestone or dolomite, some of which are either earthy or sandy. Some of the sandstone layers are highly glauconitic. The usual aspect of the formation is indicated by the section tabulated below, which is exposed along the highway about 6 miles east of Santa Rita.

Section of Bliss sandstone along highway 6 miles east of Santa Rita

[Recorded by R. E. Landon]

Limestone at base of El Paso formation.	*Feet*
Sandstone, dolomitic, crystalline	12
Sandstone, glauconitic; weathers red	6
Hidden	19
Quartzite, calcareous, thick-bedded	15
Limy beds with some shale	5
Quartzite in two beds separated by a thin layer of glauconite	11
Limestone, sandy, with lenses of coarse grit	20
Dolomite, brown, crystalline	5
Concealed	30
Sandstone and shale, glauconitic, with pebble bed at the base	10
Sandstone, vitreous, red, with 1 foot of shale at base	4
Sandstone, glauconitic, cross-bedded, dark gray or green, layers 1½ to 2 feet thick	8
Conglomerate, thin-bedded, with thin intercalations of shale in lower part	12

Within the Santa Rita area the Bliss sandstone has been penetrated at the Seven Hundred well, near the east side of the area, and it appears at the surface along the northward-trending borders of the Hanover granodiorite stock. Because of prevailing intense



Age	Formation and group	Section	Thickness (feet)	Character of rocks
Quaternary.	Gravel and sand with lava flows.		1,000+	Gravel and sand, in part consolidated, with interbedded flows of basalt.
	Unconformity			
Tertiary.	Lava flows; gravel, sand, and tuff.		2,000+	Rhyolite, latite, and andesite, with interbedded partly consolidated gravel, sand, and volcanic tuff.
	Unconformity			
Upper Cretaceous.	Andesitic breccia.		(?)	Andesitic breccia intruded by diorite and diorite porphyry.
	Unconformity (?)			
	Colorado shale.		900+	Dull-green shale and sandy shale with sandstone lenses at several horizons. Light-colored sandstone with thin beds of limestone. Dark-gray and black carbonaceous shale.
Upper (?) Cret.	Beartooth quartzite.		60-125	Quartzite with thin beds of shale.
	Unconformity			
Permian.	Abo redbeds.		0-20C	Chiefly red shale with thin beds of limestone and limestone conglomerate.
Pennsylvanian.	Magdalena group: Syrena formation.		400	Chiefly limestone with thin partings of shale. Gray and green shale.
	Magdalena group: Oswaldo formation.		400	Chiefly limestone with thin partings of shale. Massive blue limestone overlain and underlain by gray to green shale.
	Unconformity			
Mississippian.	Lake Valley limestone.		500±	White crystalline limestone with nodules of white chert. Blue limestone with nodules of black chert. Chiefly siliceous limestone with some limy shale.
Upper Devonian.	Percha shale.		150-300	Dark-gray to black fissile shale with thin limestone beds in upper part.
	Unconformity			
Silurian.	Fusselman limestone. (Map unit)		300-500	Dark-gray dolomite with some chert.
Ordovician. Upper.	Montoya limestone. (Map unit)			Light-gray dolomitic limestone with thin layers of pink chert. Dark-gray dolomite, sandy at base.
	Unconformity			
Ordovician. Lower.	El Paso limestone. (Map unit)		500±	Blue and gray limestone and dolomite, sandy in lower part.
Upper Cambrian.	Bliss sandstone.		200±	Quartzose sandstone and glauconitic sandstone, calcareous in upper part.
	Unconformity			
Pre-Cambrian.	Granite, syenite, and allied porphyries.			Granite, syenite, and allied porphyries.

COLUMNAR SECTION OF FORMATIONS IN AND NEAR THE SANTA RITA AREA.

metamorphism in the vicinity of the intrusive contacts, and especially because of poor and scattered outcrops, no little difficulty is encountered in determining the true distribution of the formation. The only place where the altered rocks are sufficiently well exposed to show the sequence of strata is along the bed of a minor watercourse northeast of the Honeycomb shaft and about 900 feet south of the Humboldt shaft.

Section of altered Bliss sandstone and overlying limestone beds northeast of Honeycomb shaft, on east side of Hanover Basin

	Feet
Montoya and El Paso limestones:	
Pink chert member of Montoya limestone	35
Massive crystalline limestone and dolomite, assigned to Montoya and El Paso formations	250
Section above uppermost layer of lean ore, 285 feet.	
Magnetite rock, thin-layered, gray tone; 2 feet of dolomite at base	19
Magnetite rock, green; 3 feet of brown dolomite at base	12
Magnetite rock, somewhat schistose; crumbles under weathering; 4 feet of dolomite at base, assigned to El Paso limestone	35
Interval not well exposed, includes layers of crumbly magnetite rock	29
Section showing lean ore, assigned to El Paso limestone, 95 feet.	
Bliss sandstone:	
Quartzite, varicolored, no magnetite, a little pyrite; four ill-defined layers	9
Layered material, sandy on weathered surfaces; carries considerable magnetite	39
Quartzite, black, much magnetite, 2 feet; hidden interval 7 feet; quartzite, black, much magnetite, 7 feet	16
Quartzite, green, dense, vitreous; breaks into smaller angular fragments	11
Schistose quartzite to granodiorite contact	95
Thickness assigned to Bliss sandstone, 170 feet.	

The schistose quartzite that occurs on the Humboldt claim west of and stratigraphically under the lowest recognizable sandstone is believed to have been derived from beds belonging to the lower part of the Bliss formation. The alternative suggestion that this body of highly metamorphosed material belongs to the pre-Cambrian crystalline complex seems improbable, in view of the structural relations of these and the overlying rocks. Near the edge of the granodiorite body the invaded rocks are uptilted so that the beds stand nearly upright, and the fact that pronounced layering in both sets of rocks is strictly conformable throughout is taken as evidence in favor of the relationship that has been suggested. This part of the section appears at the surface only within a narrow strip that extends the full length of the Humboldt claim and has a total length of about 2,000 feet.

The varicolored quartzite, which has been taken as the uppermost member of the Bliss formation, has not been identified at other localities, but in several places on both sides of the Hanover Basin proof that this quartzite is present is found in the soil or talus fragments, which are in every way like the angular fragments shed by the green quartzite beds that lie between the schistose quartzite and the black quartzite in the measured section.

Observations in the mine pits along both sides of the intrusive granodiorite have led to the conclusion that tabular bodies of rather low grade iron ore, which commonly occur next to or near the igneous contact, occupy a stratigraphic position corresponding in a general way with the group of magnetite-bearing strata shown by the Humboldt cross section and to the belief that although most of this lean ore belongs to the El Paso formation, some of it should be assigned to the Bliss.

LIMESTONE FORMATIONS OF THE ORDOVICIAN AND SILURIAN

Throughout southwestern New Mexico the Bliss sandstone is overlain by a thick succession of limestones and dolomites, which is commonly divisible upon the basis of distinct fossil assemblages into three formations corresponding to the El Paso, Montoya, and Fusselman limestones, named and described by Richardson.[14]

According to Darton,[15] the Ordovician and Silurian succession in all parts of southern New Mexico shows uniform and marked characteristic features. The Lower Ordovician El Paso limestone, which is apparently conformable with the Bliss sandstone, is in most places of unmistakable character, its conspicuous features being thin bedding, a light color on weathering, and brownish-buff reticulations on the bedding planes, caused by irregular layers of an iron-silica deposit probably due to a sea weed. Limestone and dolomite are both present. The thickness of this formation ranges from 1,000 feet in the Franklin Mountains, north of El Paso, Tex., to about 600 feet in Cooks Range, northeast of Deming, and to less than 500 feet on the west side of Mimbres Valley, east of Santa Rita.

A bed of sandstone 10 to 20 feet thick, which is noted in some sections, is taken as the basal member of the Montoya formation. Above the sandstone or, where this bed is not present, resting on the El Paso limestone there are massive beds of dark-gray dolomite.

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[14] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, El Paso folio (no. 166), 1909.

[15] Darton, N. H., Comparison of Paleozoic sections in New Mexico: U. S. Geol. Survey Prof. Paper 108, p. 34, 1918.

In the Silver City area the gray dolomite member, which is from 40 to 60 feet thick, is overlain by an 80-foot bed of dolomite which carries thin plates of pink or brown chert. Because this bed of cherty dolomite can be readily identified in separate localities it was used as a stratigraphic marker in mapping the geology of the Silver City quadrangle. The section between the Bliss sandstone and the Percha shale was divided at the base of the pink chert, so that one map unit takes in the El Paso limestone and the gray dolomite member of the Montoya and another unit includes the greater part of the Montoya and all of the Fusselman limestone.

In the type locality in the Franklin Mountains the Silurian Fusselman limestone has an estimated thickness of about 1,000 feet, but in New Mexico localities a maximum development of 220 feet has been noted in the San Andres Range and a minimum of 30 feet in the neighborhood of Silver City.

Sections measured in the Silver City quadrangle[16] show 503 feet of El Paso beds in the vicinity of Lone Mountain, 8 miles southwest of Santa Rita, and 542 feet at a locality 1½ miles west of Silver City. In the latter place the lower gray dolomite member of the Montoya is 60 feet thick, and as this member was included with the El Paso on the geologic map, the strata included by this map unit have a combined thickness of 600 feet. Adding to this figure 300 feet[17] for the upper member of the Montoya, and 40 feet for the Fusselman formation gives a thickness of 940 feet for a composite section of the pre-Devonian limestone formations.

The Bliss and El Paso formations and a good part of the Montoya are favorably exposed at localities near the highway 6 miles east of Santa Rita. Here a section measured by Wells[18] shows 164 feet of Bliss sandstone, 478 feet[19] of limestone and dolomite, 10 feet of coarse-grained cross-bedded white sandstone, 10 feet of sandy dolomite, and 65 feet of gray dolomite, sandy in the lower part, followed by 110 feet of cherty limestone or dolomite at the top of the steep scarp. If the base of the white sandstone is taken as the dividing horizon, the El Paso formation is 478 feet thick, and the lower member of the Montoya measures 85 feet. Thus at this place the beds included in the El Paso and Montoya map unit of the Silver City folio show an aggregate thickness of 563 feet, a figure only 37 feet less than that measured by Paige in the Silver City Range.

At the Apache Tejo warm springs, 12 miles southwest of Santa Rita, the log of deep well 5 (made available through the interest of

[16] Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (no. 119), p. 3, 1916.
[17] Idem, pp. 3–4.
[18] Wells, E. H., private report for Chino Copper Co., 1923.
[19] R. E. Landon, who measured a section at this place, gives 430 feet for this interval.

Mr. J. M. Sully) shows an interval of 1,150 feet between the bottom of the Devonian black shale and the top of the Bliss sandstone. Because there are no bedrock outcrops in this vicinity, the attitude of the formations has not been determined, but as it seems hardly probable that they lie in horizontal position the true stratigraphic distance between the horizons named is probably less than the measure given. The descriptions of materials given in the record of well 5 do not lead to a definite opinion regarding the top of the El Paso formation, but there is a suggestion that this horizon was reached at a depth of 1,685 feet, where the log shows siliceous brown limestone, and on this basis the apparent thickness of the El Paso would be 540 feet. The notes show a 4-foot bed of brown sandstone separated from the Devonian black shale by 140 feet of limestone, probably representing the Fusselman formation, which is known to be about 200 feet thick in the Cooks Range localities, about 25 miles to the east-southeast. This tentative division of the pre-Devonian limestone section leaves for the Montoya formation an apparent thickness of 470 feet at the Apache Tejo locality.

In mapping, the line between the two divisions has been placed at the base of a cherty dolomite member which corresponds to the pink chert beds that Paige also used as a stratigraphic marker in his mapping of the Silver City quadrangle. On the east side of the Hanover Basin a section of the rocks exposed on the second ridge south of the Humboldt mine, recorded by Harrison Schmitt,[20] places this horizon 400 feet below the bottom of the Percha shale, and the Humboldt section, given on page 13, shows 345 feet of limestone, dolomite, and iron ore between the topmost sandstone bed of the Bliss formation and the base of the cherty beds, so that a composite section gives 745 feet for the pre-Devonian limestone section. This is from 135 to 195 feet less than the thickness shown by other sections noted above and 210 feet less than the measure of the pre-Devonian limestone group at the Seven Hundred well, 2 miles to the southeast. Although the thickness of the El Paso and lower Montoya map unit is not satifactorily indicated by the record of this deep well, it is regarded as significant that in the section 6 miles east of Santa Rita this group of beds measures 563 feet. The corresponding figure in the Humboldt section is 345 feet, and other sections—for example, one near the common end line of the Humboldt and Eighty-six mining claims—show less than 200 feet of limestone and iron ore between the Bliss and the cherty dolomite.

In place of the suggestion that the general deficiency in respect to thickness and the differences in thickness at localities only a few

[20] Private communication.

hundred feet apart are original, it is held that these differences are the result of shearing and plastic flow attending intrusion of the Hanover-Fierro stock. On the west side of the Hanover Basin the division has been drawn at a horizon which is believed to be the same as that fixed upon in studying the formations east of the granodiorite stock. Here the cherty dolomite correlated with the pink chert beds of the Silver City folio are represented by crystalline dolomite carrying thin plates of yellow serpentine, grading into serpentine-magnetite rock, the so-called "tiger" ore, which may be seen in several of the mine pits on Union Hill.

Along the zone of intense metamorphism bordering the monzonite stock the masses of iron ore are tabular bodies conformable with the stratification. On Union Hill some of the best ore layers lie just under the "tiger" bed, and, so far as can be learned from observations at the surface, there are no extensive bedwise ore masses in the rocks immediately overlying this stratigraphic marker, though there are a few veinlike occurrences of magnetite. The metamorphic rocks that represent the El Paso and the lower part of the Montoya show a maximum thickness of 200 feet, and throughout the greater part of a zone 400 feet long the measure is in the neighborhood of 100 feet, less than one-fifth of the normal thickness exhibited in the surrounding region. Because the metamorphosed sedimentary rocks next to the northward-trending borders of the granodiorite now stand on edge and because the strike of the beds is essentially parallel with these borders, it is obvious that during the intrusion of the igneous mass the invaded formations were uptilted and subject to lateral thrust. The conditions were those of high temperature and deep burial, under which the plastic yielding of limestone and dolomite would be in order, and the disposition of forces and resistances was such as would have tended to the upward escape of plastic materials and concomitant thinning of the formations involved.

The El Paso and lower Montoya limestone unit is of particular interest because of the bodies of magnetic iron ore that occur in it along both sides of the Hanover monzonite stock. In general, very little in the way of metallic mineralization has occurred in the upper part of the Montoya and the Fusselman limestone, but in many places the uppermost beds, lying just under the Percha shale, have been strongly mineralized. The segregation of metal-bearing minerals in corresponding positions at the top of the Fusselman limestone is a noteworthy feature in other New Mexico mining districts, as at Hillsboro, Lake Valley, Georgetown, Lone Mountain, and localities near Silver City.

Section of pre-Devonian formations on east side of Hanover Basin

	Feet
Limestone overlain by Percha shale, greatly metamorphosed; tremolite developed around nodules of chert, presumably the Fusselman limestone	40
Dolomite and limestone, white, yellow, and blue, coarsely crystalline; carries some chert	320
Dolomite, fine-grained, crystalline, thin layers of chert basal member of the Fusselman and Montoya map unit)	40
Dolomite, crystalline, massive	250
Magnetite rock with 3 intercalated layers of dolomite 2 to 4 feet thick	95
Beds assigned to the limestone section	745
Bliss sandstone to edge of monzonite	197

PERCHA SHALE (DEVONIAN)

Throughout the southwestern part of New Mexico the Fusselman limestone is overlain by the Percha shale, named from Percha Creek, a tributary of the Rio Grande which heads in the Black Range west of Hillsboro and Kingston. Good exposures of the formation are to be found in the eastern part of the Silver City quadrangle near Georgetown and along highway 84, 5 miles east of Santa Rita. At these localities the lower part of the section shows about 100 feet of black fissile shale, and above this about 80 feet of gray shale with calcareous nodules, grading into limy shale and fossiliferous shaly limestone 20 feet thick, a total estimated thickness of about 200 feet.

In the Santa Rita area the Percha shale is not exposed outside of the Hanover Basin, where all the formations exhibit the effects of metamorphism. The ringwise distribution of the shale outcrops shown on the geologic map reflects the existence of a marked structural dome roughly symmetrical with the oval Hanover Basin but somewhat shorter. Along the eastern outcrop thin porphyry sills occur at the top of the Percha shale toward the south end of the belt and about 40 feet above the base, in the vicinity of the Jim Fair iron mine. On the other side of the dome, west of Union Hill, a porphyry sill, which is locally 400 feet thick, follows a horizon about 20 feet above the bottom of the formation for nearly 4,000 feet along the strike. Toward the north end of this prophyry area, on the Queen Lil and Engineer claims, poor exposures suggest that the intrusive mass may cut upward across the stratification.

In a patch of country south of the Continental shaft, on the Anson S. and Engineer claims, the Percha shale does not appear between outcrops of the older and younger formations. North of the Anson S. claim the lowermost member of the Lake Valley formation is represented by garnet rock capping the hill east of the Continental shaft and overlying the Percha formation in normal succession. From the surface distribution of the garnet rock and the shale it is evident that the strata dip toward the Barringer fault, and this conclusion checks with the fact that the black shale appears in the tunnel-level workings northwest of the Continental shaft. A structure section through the shaft gives the Percha shale an estimated thickness of 100 feet, compared with a determined minimum of 230 feet in the block of ground adjacent to the lower end of the monzonite stock south of Hanover. Toward the north the Percha shale probably occurs on the McCarthy claim, but in this neighborhood exposures are all but lacking, so that the distribution of formations shown upon the geologic map is subject to correction. North of Fierro, on the Hugo and nearby claims, the mapping can be accepted as essentially correct.

In the Santa Rita area the older formations of the Paleozoic succession are exposed on both sides of the elongated mass of granodiorite which has been called the Hanover-Fierro stock, but because all the beds that lie stratigraphically below the Percha shale have been greatly affected by metamorphism, the idea of dividing the limestone section into parts that might correspond with the El Paso, Montoya, and Fusselman formations has been abandoned in favor of a twofold division.

The thickness of the Percha formation ranges from perhaps 100 feet in the Continental mine to 230 feet in drill holes in the neighborhood of the Republic shaft and 300 feet in the northern part of the eastern belt of outcrops. West of Union Hill and south of Badger no. 1 claim a measured section shows 220 feet of shale above the porphyry sill, to which there is to be added about 20 feet for baked shale below the sill, a total of 240 feet. In the middle part of the eastern belt of outcrops measured sections show a range in thickness from 140 to 175 feet, and around the south lobe of the Hanover stock several diamond-drill cores show about 230 feet. An inspection of samples of drill cuttings from the Seven Hundred well, northeast of Santa Rita, indicates a thickness of about 190 feet for the shale formation at this place.

DIVISIONS OF THE CARBONIFEROUS SYSTEM

The †Fierro limestone[21] was defined in the text of the Silver City folio as a local map unit covering the rocks belonging to the Mississippian and Pennsylvanian series of the Carboniferous system. On this basis the †Fierro included beds equivalent to the Lake Valley

[21] A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U. S. Geological Survey. Quotation marks, formerly used to indicate abandoned or rejected names, are now used only in the ordinary sense.

limestone (Mississippian)—also the Kelly limestone—and the Magdalena group (Pennsylvanian) of other districts in New Mexico. The distribution of the †Fierro shown on the folio map published in 1917, however, makes it include not only the formations named but also, in the eastern part of the quadrangle, redbeds not mentioned in the folio text, which are doubtless to be correlated with the Abo sandstone, the lowermost Permian formation in central and eastern New Mexico. In the Continental Divide near Silver City the Abo redbeds are missing, but they appear beneath the Beartooth quartzite in the Santa Rita area and are prominently developed farther to the east and southeast.

The geologic map accompanying the present report (pl. 1) shows four Carboniferous formations—the Mississippian Lake Valley limestone, the Pennsylvanian Magdalena group, divided into an upper (Syrena) formation and a lower (Oswaldo) formation, and the Permian Abo redbeds. The †Fierro limestone of earlier reports having now been differentiated into several units, the name is considered to be no longer useful and is discarded.

Measured sections of the Lake Valley limestone show a maximum thickness of 500 feet at a locality west of Silver City. In the Santa Rita area the Magdalena group is 800 feet thick, and 2 miles east of the copper mines the Abo redbeds measure nearly 200 feet.

LAKE VALLEY LIMESTONE (MISSISSIPPIAN)

The Lake Valley limestone, of lower Mississippian age, bears the name of the Lake Valley mining district, where an incomplete section shows 210 feet of limestone underlain by Percha shale. In the Cooks Peak region[22] the formation is about 500 feet thick. It comprises an upper member of gray, more or less cherty, massive to slabby limestone with intercalated layers of limy shale and a 150-foot basal member of bluish gray limestone which carries some chert.

According to Paige's interpretation of the †Fierro limestone section,[23] the Lake Valley formation is about 500 feet thick in the vicinity of Silver City, and in a section along the highway 5 miles east of Santa Rita the thickness is 497 feet.

Section of Lake Valley limestone 5 miles east of Santa Rita

[Recorded by R. E. Landon]

	Feet
Shale, 10-foot bed at base of Magdalena group.	
Limestone, light gray, coarse-grained except near base; white chert in upper part; many crinoid stems	55
Limestone, thin-bedded or shaly; 2 feet of coarse-grained limestone at base	17

[22] Darton, N. H., U. S. Geol. Survey Geol. Atlas, Deming folio (no. 207), p. 5, 1917.
[23] Paige, Sidney, op. cit. (Silver City folio), p. 5.

Section of Lake Valley limestone 5 miles east of Santa Rita—Continued

	Feet
Limestone, dark gray, slightly shaly, with nodules of limestone and chert	10
Limestone, white, crystalline, thick-bedded	50
Limestone with chert, somewhat shaly; basal bed of the crinoidal limestone member	5
Limestone, gray with reddish cast in part, fine-grained, somewhat shaly toward top; some chert	130
Limestone, fine-grained, medium- to thin-bedded, reddish where thin-bedded	50
Limestone, blue, fine-grained, with chert layers in upper part	35
Limestone, blue-gray, thick-bedded in upper part, thin-bedded below; basal bed of lower blue limestone member	20
Limestone, dark gray to blue, with nodules of limestone and black chert; abundant Bryozoa	60
Shale, gray, calcareous, with thin layers of limestone, especially in lower 10 feet	65
Shale at top of Percha shale.	
	497

In the Santa Rita area the Lake Valley limestone does not appear at the surface outside of the area of marked structural disturbance adjacent to the Hanover stock of granodiorite. Besides minor outcrops near the Continental and Hanover mines, essentially complete sections are to be found along separate belts on opposite sides of the northern or Fierro lobe of the stock, and to the west and south of the Hanover lobe the uppermost member of the formation is exposed along the crest of a curving anticline that extends around three sides of this lobe of the intrusive mass. At three places on the east side of Hanover Valley thicknesses ranging from 335 to 450 feet have been recorded by E. H. Wells, who gives the following section as applicable to this general locality:

Composite section of Lake Valley limestone east of Hanover Valley [24]

	Feet
Limestone, white, grayish, or light blue, coarsely crystalline, massive; many crinoid stems	175
Limestone, medium to dark blue, fine to medium grain; ellipsoidal and irregular black chert nodules	190
Limestone, blue, slightly shaly, fine-grained, with thin layers of chert	40
Limestone, light grayish blue, massive, with irregular chert layers and nodules	30
	435

[24] Quoted with changed wording from Wells, E. H., The geology and ore deposits of the Chino property, Santa Rita, N. Mex., unpublished report, 1923.

The following sections measured by Harrison Schmitt are given through the courtesy of the Empire Zinc Co.:

Section of Lake Valley limestone on second ridge south of Humboldt shaft

[Recorded by Harrison Schmitt]

	Feet
Shale at base of Magdalena group.	
Limestone, gray to pink; many crinoid stems	35
Limestone, massive, coarse-grained, crystalline; few fossils	40
Limestone, white, coarse-grained, crystalline, to base of crinoidal limestone member	40
Limestone, blue, medium- to thin-bedded; carries black chert; where thin-bedded carries crinoid stems. A shaly bed 10 feet below top, and 10 feet of calcareous shale at base	182
Limestone and siliceous limestone, irregularly interbedded	41
Limestone, siliceous, with small lenses of blue limestone	30
Limestone, siliceous, thin layers interbedded with softer material	30
Shale at top of Percha formation.	
	398

Generalized section of Lake Valley limestone west side of granodiorite stock

[Recorded by Harrison Schmitt]

	Feet
Crinoidal or white crystalline limestone member	120
Blue limestone member	190
Siliceous limestone member	100
	410

In the Empire Zinc Co.'s ground diamond-drill explorations have shown that the crinoidal limestone member is from 130 to 140 feet thick along the crest of the curving anticline which encircles the Hanover lobe of the stock, but that nearby on the limbs of this fold these beds are usually much thinner and in places the thickness is not more than 80 feet. These observations afford acceptable evidence that the crinoidal limestone has been locally subject to plastic deformation, and this conclusion serves to corroborate the opinion that the abnormal thinness of the Lake Valley and older limestones in this area is to be explained as the result of deformation of the same type.

MAGDALENA GROUP (PENNSYLVANIAN)

OSWALDO AND SYRENA FORMATIONS

The name "Magdalena", from the Magdalena Mountains in Socorro County, was proposed in 1907 [25] to designate the lower part of

[25] Gordon, C. H., Notes on the Pennsylvanian formations in the Rio Grande Valley, N. Mex.: Jour. Geology, vol. 15, p. 806, 1907.

a 5,000-foot succession of limestone, shale, and sandstone beds occurring in the Rio Grande Valley of New Mexico. At first the whole section was placed in the Pennsylvanian series, but as the result of later studies the upper part, with the Abo sandstone at its base, is now assigned to the Permian series. In the central part of the State the Magdalena group [26] is represented by the Sandia formation, about 650 feet thick, composed principally of shale with intercalated beds of limestone, sandstone, and conglomerate, and above this the Madera limestone, at least 600 feet thick, composed of compact blue limestone in massive beds separated by layers of shale.

In the Silver City region and in the Black Range, 20 miles to the east, the maximum thickness of the Magdalena group is probably less than 900 feet, and its stratigraphic constitution is so notably different that divisions corresponding with the Sandia and Madera formations have not been recognized. However, in course of the present study of the Santa Rita area it has been found convenient to divide the section into two parts, which have been mapped as the Oswaldo formation below and the Syrena formation above, the names chosen being those of patented mining claims about 1 mile south of Hanover post office. The Syrena claim includes the common corner of secs. 21, 22, 27, and 28, T. 17 S., R. 12 W., and the Oswaldo claim adjoins it on the northwest.

Although there is a considerable stratigraphic hiatus above the Lake Valley limestone throughout the Silver City region, the beds above and below the break appear to lie in parallel position, and the only physical evidence that can be cited as suggestive of unconformity is a bed of white chert which occurs in many localities at the top of the crinoidal limestone member of the Lake Valley formation. Locally, the strata that are here assigned to the Magdalena group are succeeded by red sediments that evidently belong to the Abo formation, but elsewhere these red strata are absent and the Upper (?) Cretaceous Beartooth quartzite lies upon beds of Magdalena age. In the southwestern part of the Santa Rita area the upper part of the Syrena formation, to a depth of about 100 feet, had been cut away by erosion before the Beartooth formation was deposited, whereas only a short distance east of the Chino copper mines, fully 200 feet of redbeds are present between the top of the Syrena section and the bottom of the Beartooth.

Except in the northeastern part of the area, where a bed of coarse-grained sandstone occurs about 100 feet above the base of the section, the Oswaldo formation is made up entirely of limestone and shale.

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[26] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 233, 1910.

A bed of shale from 20 to 30 feet thick occurring at the base of the formation is followed by 80 to 90 feet of massive blue limestone, above which comes 300 feet of limestone occurring in relatively thin layers, some of which are separated by beds of shale. Because these partings are rarely exposed, the proportions in which shale and limestone are present cannot be stated, but it seems that the shale may constitute something like 15 percent of the whole.

The Syrena formation is also composed of limestone and shale, the limestone predominating. Immediately overlying the Oswaldo formation is a body of shale from 100 to 130 feet thick, and at two or three horizons in the lower part of this member there are thin beds of limestone made up of nodules showing the concentric structure which is characteristic of certain forms of the lime-depositing algae. Above the shale member is a succession of limestone and shale that shows a maximum thickness of 260 feet in places where it is capped by the Permian redbeds.

The surface distribution of the two Pennsylvanian formations within and to the east and northeast of the Santa Rita area reveals the general structure of the area as that of a broad arch or anticline with its axis trending southwest. On both sides of the north lobe of the Hanover-Fierro stock the Oswaldo beds have been cut out by the Barringer fault, but aside from this gap the formation appears along the crown of the arch, and the overlying Syrena beds crop out along flanking bands which converge and come together around the gently plunging southwest end of the arch.

Division of the Pennsylvanian series into two formations affords a satisfactory basis for areal mapping, but in detailed work by the geologic staff of the Empire Zinc Co. the section between the Lake Valley limestone and the Abo redbeds has been represented as consisting of six divisions, which it will be convenient to speak of as members of the Oswaldo and Syrena formations, as indicated in the following table:

Subdivisions of the Magdalena group as differentiated by the geologic staff of the Empire Zinc Co.

	Feet
Syrena formation, 390 feet:	
Don limestone	260
Mountain Home shale	130
Oswaldo formation, 405 feet:	
Banded limestone	80
Upper blue limestone	210
Marker sill [porphyry], 50 feet.	
Middle blue limestone	85
Parting shale	30
	795

The thicknesses given in the table apply to the section between Buckhorn Gulch and Humboldt Mountain, where Abo redbeds occur between the Syrena formation and the Beartooth quartzite.

On the east side of Hanover Creek a section measured by E. H. Wells shows a stratigraphic thickness of 804 feet between the base of the Beartooth quartzite on Topknot Hill (south of Santa Rita) and the marker sill that occurs above the middle blue limestone members. The upper part of this section shows 116 feet of highly altered sediments which Wells regarded as part of the Pennsylvanian but which are now assigned to the Abo redbeds (Permian), so that the Pennsylvanian part of the section measures 688 feet. The two basal members of the Oswaldo formation cannot be satisfactorily measured in nearby localities, but from the log of the Seven Hundred well, on the Joy claim, it seems that their combined thickness may be about 110 feet, which gives an estimate of about 800 feet for the stratigraphic distance between the Lake Valley limestone and the Abo redbeds. Because the measures of this section and that of the Humboldt section correspond so closely, it may be assumed that here as there the thickness of the Oswaldo formation is in the neighborhood of 410 to 420 feet, and that of the Syrena formation perhaps 380 to 390 feet. On this basis the horizon of the marker sill would lie from 300 to 310 feet below the Oswaldo-Syrena parting, an estimate which checks fairly well with the fact that the record of a diamond-drill hole near the south side of the Kearney claim shows that a body of fine-grained porphyry, 35 feet thick, was entered at a depth of 315 feet. Observations in the vicinity of this locality shows that the beds dip about 20° south and that the altered rocks which appear at the surface belong near the top of the Oswaldo formation. With the stated inclination of the beds a vertical depth of 315 feet corresponds with a stratigraphic thickness of about 280 feet.

A third estimate of the thickness of the Pennsylvanian section is based on the record of a diamond-drill boring near the north end of Nellie Patterson claim 5 and about 350 feet northwest of the Hobo fault, made available through the courtesy of the local agents of the American Smelting & Refining Co. The distances given in the section have been scaled from the graphic log showing the results of this exploration.

Section indicated by record of diamond-drill exploration on Nellie Patterson claim 5

	Feet
Beartooth quartzite	60
Interval	225
Porphyry sill	10

Section indicated by record of diamond-drill exploration on Nellie Patterson claim 5—Continued

	Feet
Interval	105
Porphyry sill	90
Interval	440
Porphyry sill, "marker sill"	20
Interval	40
Barren quartz	4
Crinoidal limestone	80
Limestone below crinoidal member	430
	1,504

If the sills of porphyry are omitted the figures given indicate for the Pennsylvanian series a thickness of 810 feet, but the possibility that the section may not be complete is suggested by the fact that the original drawing shows a fault at the place where the 4 feet of barren quartz occurs, which may signify that the quartz was regarded as vein filling by the observer who kept the log. An alternative possibility would be that the material noted as quartz may be white chert like that which may be noted at the top of the Lake Valley formation in several places and which occurs as a layer from 4 to 8 feet thick in the Combination mine, about 4,400 feet northeast of the locality here under consideration. From a careful study of the core samples it should be possible to decide concerning the presence or absence of the chert bed and of the parting shale member that ordinarily occurs above it. If this shale bed is present the need for assuming a fault disappears.

It is believed that the two bodies of porphyry shown in the upper part of the Nellie Patterson section correspond with sills that appear at the surface in the country west of the Mirror fault and on the Blackhawk tract, to the northeast. The 90-foot sill of the section corresponds with a sill 65 feet thick occurring in the vicinity of the Combination shaft at a horizon about 60 feet above the Oswaldo-Syrena parting.

ABO REDBEDS (PERMIAN)

Redbeds that are assignable to the Abo formation of the Permian series on the basis of lithology and stratigraphic position are locally present within and to the east of the Santa Rita area, although they escaped the attention of geologists until 1923, when E. H. Wells examined and measured a 200-foot section of them about 5 miles southeast of Santa Rita. This section, which has been made available through the courtesy of Mr. J. M. Sully, is here given:

Section of Abo redbeds 5 miles southeast of Santa Rita

	Feet
Shale, red, upper part sandy	40
Limestone conglomerate, pebbles of limestone with some chert, diameters three-eighths inch or less	3
Shale, red	20
Limestone, mottled purple and gray, brown on weathered surfaces	4
Shale, red	12
Limestone, mottled gray and purple	12
Shale, red	60
Limestone conglomerate	4
Shale, red	41
Limestone, dark gray, fine-grained	5
Shale, red	6
	207

Somewhat thinner but otherwise similar sections may be seen south of highway 180 about 1½ miles east of Santa Rita, and near the head of Shingle Canyon, about 2 miles northeast of Fierro. In both places the formation is made up largely of red fine-grained calcareous and earthy sandstone with intercalated layers of earthy limestone and thin beds of limestone conglomerate containing conspicuous colonies of algae. Similar beds containing algae in redbeds in the vicinity of Cooks Peak have been correlated with the Lobo formation of the Florida Mountains by N. H. Darton and tentatively regarded as of Triassic age. According to unpublished observations by Harrison Schmitt the redbeds at Cooks Peak and those of the Shingle Canyon locality show identical characteristics, and as there is hardly room for doubt that the redbeds in the region between Fort Bayard and the Mimbres Valley must be correlated with the Abo formation rather than with the Lobo beds, it seems consistent to correlate those at Cooks Peak with the Permian Abo sandstone.

Within the Santa Rita area essentially unaltered Abo redbeds have been noted only on the north side of the Beartooth Creek drainage basin, where the usual thickness does not exceed 50 feet. Remnants of the Abo can also be identified between the Syrena and Beartooth formations on the hills north of Santa Rita, but here they are so greatly metamorphosed that their identity is not apparent to the casual observer. It is probable that the formation is not greatly altered in the extreme eastern part of the area south of highway 180, where the section is hidden by a mantle of loose debris, but the only localities where redbeds in their normal character have been observed are in the Beartooth drainage basin and in the northeast corner of the area where they appear along the northwest side of the regional anticline and between the two forks of the Barringer fault.

In the ore pits at Santa Rita a body of metamorphosed rock, made up principally of dark-green chlorite and magnetite, which lies just below the Beartooth quartzite and in contact with the main stock of granodiorite, is believed to represent the Abo redbeds, and material of the same sort and in like stratigraphic position within the zone of intense metamorphism on the west side of the Hanover-Fierro stock, near the Modoc mine, where the estimated thickness of the section is about 120 feet, has also been mapped as Abo. To the north of Sully School on Topknot Hill and also on Humboldt Mountain measured sections show about 120 feet of greatly altered strata which can be assigned to the Abo with confidence, in spite of the fact that their normal features have been almost entirely masked. In both localities the red sandstones and sandy shales have been converted into dark-purple or dark-green hornstone, and at many places noteworthy amounts of epidote have been developed. Where the Abo redbeds have been shown in localities not mentioned above, the mapping is based upon at least a few outcrops of metamorphic rocks resembling those to be seen on Topknot Hill and upon ascertained structural features in the neighborhood.

MESOZOIC FORMATIONS

Two Mesozoic formations are described in the Silver City folio, the Beartooth quartzite and the Colorado shale. The same formations are recognized and mapped in this report.

BEARTOOTH QUARTZITE

The Beartooth quartzite was named from Beartooth Creek, in the Fort Bayard Military Reservation near the west boundary of the Santa Rita area. It lies unconformably either upon the Abo redbeds, of Permian age, or upon the Syrena formation, of Pennsylvania age, and is overlain conformably by the Colorado shale. It is made up of beds of fine-grained sandstones a few inches to 25 feet thick, separated by relatively thin partings of shale or sandy shale. Nearly everywhere the beds of sandstone, especially in the upper part of the formation, have been changed to quartzite by silicification.

The following section, exposed about 4½ miles southeast of Santa Rita, is given to show the character of this formation in the general region, the details of its stratigraphy not being observable within the Santa Rita area because of very poor exposures. The thickness of the formation at this locality is essentially the same as that given in the Silver City folio for a section exposed near Silver City.

Section of Beartooth quartzite 4½ miles southeast of Santa Rita

[By E. H. Wells, 1923]

	Feet
Sandstone, massive, vitreous, medium- and coarse-grained, containing also some conglomerate; gray and pink, weathering in part to reddish brown and black; probably corresponds to upper part of Beartooth quartzite at Santa Rita	25
Sandstone and shale, poorly exposed	18
Sandstone, massive, thick-bedded, gray and buff, weathering to red and black	25
Shale, black, carbonaceous, laminated	8
Sandstone, massive, vitreous, medium-grained to fairly coarse-grained, gray to buff; prominent bedding planes 6 inches to 3 feet apart	20
Shale, sandy, gray	2½
Sandstone, massive, gray	2
Shale, slightly carbonaceous	2½
Sandstone, massive, gray	3½
Shale, black, laminated, highly carbonaceous; prospected for coal	3
Sandstone, massive, light gray	4½
Shale, black and gray, laminated, highly carbonaceous in part; prospected for coal	4
Shale, laminated, red and gray	2
Sandstone and shale, red and gray	6
Sandstone, shaly	4
Shale, gray	2
Sandstone, medium-grained, brown, with some red-mottled areas; underlain by red shale of Abo redbeds	10
	132

Within the Santa Rita area the formation is about 60 feet thick, and a thickness of about 125 feet is probably the maximum. A thin bed of chert conglomerate, noted at several places, occurs at the top or 4 to 8 feet below the top of the formation.

In the Santa Rita area the Beartooth quartzite is exposed along the flanks of the broad anticline or arch that plunges toward the southwest, but owing to widespread faulting and intricate invasion by a variety of stocks and dikes, the formation is greatly disturbed. A few isolated inliers, of which the top of Humboldt Mountain is a conspicuous example, mark the crest of the arch, which in most places is eroded well down into the lower part of the Pennsylvanian series. The distribution of the formation is exhibited by the geologic map except in a few areas, mostly near Santa Rita, where it has been necessary to generalize because all efforts to acquire true understanding of the local features have failed.

According to Paige,[27]

> No fossils have been found in the formation. It is similar in many respects to the Dakota sandstone, but Darton has obtained fossils belonging to the Washita group of the Comanche (Lower Cretaceous) in the Deming quadrangle, immediately southwest of the Silver City area. For the present, therefore, the age of the Beartooth quartzite remains in doubt, but it is tentatively regarded as Upper Cretaceous.

A thin bed of chert conglomerate noted at several places near or at the top of the formation suggests the possibility of a boundary between the Upper and Lower Cretaceous series.

COLORADO SHALE

The Colorado shale bears the name of the State of Colorado, where rocks of this age are characteristically developed. Throughout the general region of which the Santa Rita area forms a part the formation lies upon the Beartooth quartzite, and its upper limit is either the present land surface or an older land surface which is now buried beneath the volcanic rocks of the region, so that the full sequence is nowhere to be observed.

As exhibited at different localities in the Santa Rita area, the formation comprises three rather well defined divisions—a lower carbonaceous shale member, a middle member characterized by prominent beds of light-colored calcareous sandstone, and an upper member made up of prevailing dull-green shale, sandy shale, and fine-grained sandstone. Several measurements of the lower member within the quadrangle indicate that it is everywhere about 200 feet thick. At the base there is from 80 to 90 feet of well-laminated dark-colored clay shale; above this 25 to 35 feet of shale alternating with thin beds of sandstone and sandy limestone, some of which carries well-preserved fossil shells, followed by about 90 feet of clay shale nearly black in the lower part but sandy and gray toward the top.

Exposures of the middle member in the vicinity of Gold Creek show 130 feet of sandstone occurring in rather massive beds. The sandstones are characteristically calcareous, and layers of sandy limestone a foot or more in thickness occur 15, 45, 85, and 110 feet above the base of the middle member. The limestone beds are in places fossiliferous. No detailed measurement of the middle member of the formation was possible, but it has an estimated thickness of 520 feet at the edge of the mapped area, east of Santa Rita, where stratigraphic details are obscured by lack of outcrops.

The upper member comprises dull-green shales, sandy shales, and sandstones. In the eastern part of the area these beds have an

[27] Paige, Sidney, op. cit. (Silver City folio), pp. 5–6.

estimated thickness of 220 feet. The Colorado shale as a whole, measured in the locality last mentioned, is 920 feet thick.

The Colorado shale lies stratigraphically above the Beartooth quartzite. In the northern part of the area there is a broad exposure of shale between lava ranges to the north and a prominent fault to the south. In the southern part of the area faulted and in places metamorphosed blocks of Colorado shale are variously disposed, as indicated on the map.

The fossils in the following list, identified by T. W. Stanton, have been found in the Silver City quadrangle. Those from locality 4 were found near the west boundary of the Santa Rita area by A. C. Spencer, and those from localities 1, 2, and 3 were collected by Sidney Paige. The impure limestone that carries *Gryphaea newberryi* has been noted at several places in the southern part of the Santa Rita area and was thus a very useful horizon marker.

Fossils from Colorado shale

	1	2	3	4		1	2	3	4
Ostrea sp.		X	X		Corbula sp.		X	X	
Gryphaea newberryi Stanton	X			X	Plicatula cf. P. hydrotheca White				X
Exogyra columbella Meek				X	Astarte sp.				X
Trigonarca obliqua Meek		X			Gyrodes depresa Meek		X	X	
Cardium pauperculum Meek?		X	X		Gyrodes sp.				X
Tapes? sp.			X		Pugnellus fusiformis (Meek)?		X	X	

The horizons are from 85 to 115 feet above the Beartooth quartzite.

1. 4 miles north-northwest of Silver City, east fork of Silver Creek near road.
2. 4 miles northwest of Silver City, about 300 feet above Beartooth quartzite.
3. About 1 mile north of west summit of Lone Mountain, 100 feet above Beartooth quartzite.
4. Near quarter-section monument on west side of sec. 31, T. 17 S., R. 12 W.

The above-named fossils indicate a horizon near the base of the Colorado group as represented in the lower part of the Mancos shale of southwestern Colorado and adjacent parts of New Mexico, Utah, and Arizona.

TERTIARY FORMATIONS

GRAVEL, SAND, AND TUFF

Accumulations of ill-sorted gravel, sand, and tuff, regarded as of Tertiary age, in places underlie and in places are interbedded with the rhyolite and andesite lavas. The beds beneath the lavas consist of thin to thick bedded friable sandstone and tuff in which the lowermost materials have been derived mainly from the underlying intrusive rocks or sediments. (See pl. 4.) Most of the beds are light-colored, some being nearly white and others drab or brown. In some layers fragments of chert occur, but except at the very base pebbles of other sedimentary rocks are not present. In most places the lowest beds are hidden by talus so that their nature cannot be observed, but at a few points there are exposures of loose gravelly material made up of rock fragments mainly of very local derivation. A prospect near the divide between the San José and Lucky Bill mines shows more than 30 feet of unconsolidated shingle or gravel made up of shale and porphyry pebbles derived from formations now exposed in the area just to the north of the locality. Outside the area mapped but near its southwest corner, at the same horizon, there are loose deposits consisting of pebbles and boulders of magnetic iron ore and of garnet and epidote rock which must have been derived from a source near Hanover or near Santa Rita and the occurrence of which indicates that before the volcanic epoch the principal drainage lines of the immediate district were much the same as at present.

The aggregate thickness of the tuffs and sandy beds varies greatly from place to place, mainly because of irregularities in the prevolcanic topography. Deposition of the formation obliterated this earlier topography, filling hollows, overtopping minor ridges, and flanking higher hills, so as to form a fairly even floor over which the lavas were afterward extruded. South of the open pits at Santa Rita there is no tuff beneath the rhyolite, and the old erosion surface has a gentle westward slope. Farther west the fragmental deposits again appear, and the surface on which they lie slopes 400 feet in a distance of less than half a mile.

In the northern part of the area the lavas rest as a rule directly upon the pre-Tertiary formations except in the vicinity of Avalanche Peak, where there is a thick deposit of coarse gravel containing a large amount of igneous material. The bedded sand and gravel are well exposed in the topographic basin south of Hanover, where down-faulting has preserved the beds from erosion. (See pl. 5, *B*.)

IGNEOUS ROCKS

VOLCANIC ROCKS OF UPPER CRETACEOUS AGE

Within the northwest corner of the Santa Rita area, in a tract covering less than a square mile, there occurs a complex of breccias and dikes of andesitic and dioritic composition between the Tertiary lavas on the north, by which they are overlapped, and Colorado shale on the south. This complex extends far to the west of the Santa Rita area and is exposed for many square miles.[28] A part of it is tentatively regarded as a group of flow breccias of Upper Cretaceous age interbedded with Colorado shale. The dikes cut the flow breccias and the Colorado shale and are earlier than the Tertiary lava flows by which the complex is overlapped, but their age cannot be precisely determined. The inference that the flow

[28] Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (no. 199), p. 7, 1916.

breccias are local representatives of a period of active and widespread volcanism during Upper Cretaceous time is supported by the presence of a thick series of similar deposits in the Upper Cretaceous of the Aravaipa and Stanley mining districts of Graham County, Ariz.[29]

INTRUSIVE ROCKS OF LATE CRETACEOUS OR EARLY TERTIARY AGE

Accompanying the invasion of the andesitic and dioritic dikes mentioned in the preceding section or perhaps somewhat later, masses of quartz diorite porphyry invaded the sedimentary rocks as stocks and sills, and these in turn were cut by stocks and dikes of granodiorite porphyry. It is known from observations in the Santa Rita area and elsewhere in the Silver City quadrangle that all these intrusions considerably antedated the flows of Tertiary lava.

QUARTZ DIORITE PORPHYRY

Sills or intrusive sheets of medium-gray fine-grained to moderately coarse-grained porphyritic quartz diorite occur parallel or nearly parallel to strata of the Percha, Oswaldo, and Syrena formations and as sills or laccoliths in the Colorado shale. The porphyry contains relatively large grains or phenocrysts of plagioclase, hornblende, and quartz in a fine-grained groundmass composed essentially of the same minerals.

The sills occurring in the Paleozoic formations range in thickness from a few feet to not less than 400 feet. The thicker ones occur northeast of Fierro, west of Union Hill, south of Copper Flat, and in the southern part of the area. The thinner ones occur in Buckhorn Gulch, east of the Hanover Basin, and north and northeast of Santa Rita. Although in places the sedimentary rocks in contact with the sills are strongly altered, in the main the metamorphism is related not to these intrusions themselves but to a later invasion of igneous material. The extensive mass that invades the Colorado shale has been called the Fort Bayard laccolith.

The geologic map of the Silver City folio shows that the outcrop of the laccolith extends in a belt 1 to 2 miles wide for about 8 miles from Central to a point east of the Kneeling Nun. To the south the mass is overlapped by Tertiary lava and Quaternary gravel, but outcrops 4 miles southwest of Central, taken together with the belt just described, suggest that the laccolith was roughly oval in form and that it covered an area of at least 50 square miles. Such

[29] Ross, C. P., Geology and ore deposits of the Aravaipa and Stanley mining districts, Graham County, Ariz.: U. S. Geol. Survey Bull. 763, pp. 25, 26, 51, 1925.

studies as have been made indicate that the mass was thickest at a point south of Santa Rita, now covered by Tertiary lava, and that the mass extended to the north of Santa Rita to an unknown but not great distance.

On the east side of Santa Rita Creek, on the Silver Dollar mining claim, its thickness is 160 feet. A diamond-drill exploration near the Bull Frog shaft 5, in Gold Gulch, reveals a thickness of 500 feet. In the Lucky Bill and Groundhog mines it has been penetrated 400 feet without reaching the base, and a churn-drill hole in the country south of Santa Rita shows a depth of at least 900 feet below the present surface. On the ridge that extends north from the Kneeling Nun the mass breaks across the beds of Colorado shale for at least 600 feet, and in the southeast section of the mine pits at Santa Rita the rock cuts across the Abo, Beartooth, and Colorado formations for a stratigraphic distance of at least 300 feet. This observation of crosscutting together with the great thickness south of the present exposed edge of the intrusive, suggests that one of the feeders of the laccolith may have been located in this general region.

The rock of the Fort Bayard laccolith is essentially typical of that forming the other sills. It is gray or greenish gray, fine-grained, and very slightly porphyritic, through the presence of small phenocrysts of feldspar. For the most part specimens of rock from different intrusions do not vary greatly in general appearance, though the rock of the sill west of Union Hill is finer and less even grained than that of the other sills. In many places the rocks of the sills contain much epidote and instead of having the usual grayish color are distinctly green. Thin sections examined under the microscope show that the rock of the sills is everywhere greatly altered. Originally it was composed essentially of oligoclase, hornblende, and quartz, with magnetite and apatite as accessory minerals. Now the hornblende is as a rule completely altered to chlorite or to chlorite, calcite, and epidote, and the oligoclase is in part changed to sericite. Phenocrysts of oligoclase, rarely more than 3 millimeters in diameter, are set in a groundmass composed of smaller well-formed crystals of oligoclase, quartz, and chlorite derived from hornblende.

Two stocks of porphyritic quartz diorite occur in the northwest quarter of the area, north of the Barringer fault. (See pl. 1.) They break across the beds of the Colorado formation, and locally lava flows rest upon them. The Hermosa stock, named from Hermosa Mountain, occupies an area 2 miles long and from half a mile to 1 mile wide. The rock is greenish-gray porphyry, usually containing phenocrysts of black hornblende in a fine-grained groundmass which is itself slightly porphyritic through the presence of small phenocrysts of feldspar. The hornblende crystals have the form of narrow prisms, some of which are as much as 20 millimeters long. Where the hornblende phenocrysts are sparse or essentially absent the rock has nearly the same appearance as the porphyry of the sills that have been described but is of a slightly darker tone.

Thin sections of fairly fresh material examined under the microscope show oligoclase, primary hornblende partly altered to chlorite, colorless hornblende secondary after well-shaped crystals of pyroxene, a little quartz, rather abundant magnetite, and an occasional crystal of apatite. The texture is markedly porphyritic with respect to the altered pyroxene and with respect to abundant crystals of oligoclase, whose diameters range from 2 to 5 millimeters. The groundmass, which forms not more than one-fourth of the rock, is composed of minute crystals of oligoclase and irregular grains of quartz. In specimens containing chlorite this mineral has been derived mainly through the alteration of primary hornblende rather than from pyroxene or secondary hornblende. Alteration products include the hornblende and chlorite mentioned above and also epidote, most of which replaces pyroxene but some of which replaces hornblende and oligoclase.

The rock of the stocks that lie west and north of Hanover Mountain is a dark bluish-gray fine-grained porphyry, which on weathered surfaces shows phenocrysts of feldspar and small pits from which mica has weathered out. Thin sections examined under the microscope show that the rock is composed mainly of albite-oligoclase, other constituents being quartz, biotite, magnetite, and apatite. The feldspar occurs both as phenocrysts from 3 to 5 millimeters long and as small laths that form a trachytic groundmass. The biotite occurs as minute crystals and in the form of aggregates with oval cross sections. Quartz occurs only as a minor constituent of the groundmass.

GRANODIORITE AND GRANODIORITE PORPHYRY

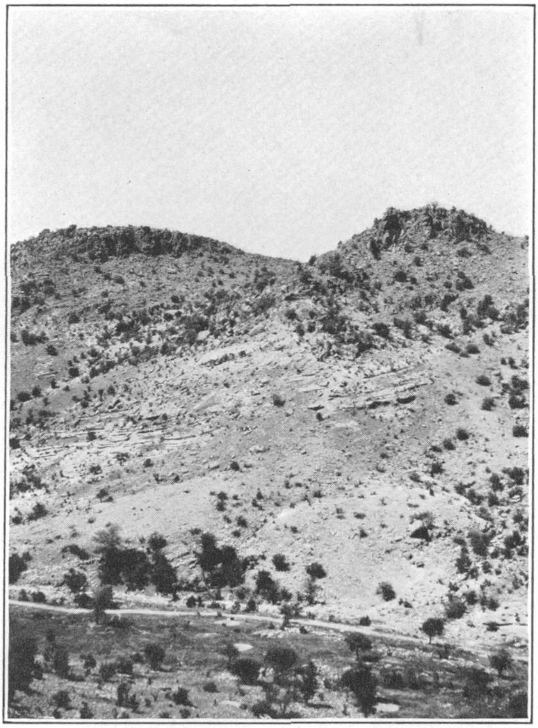
Granodiorite in the Santa Rita area occurs as stocks and dikes. The largest mass is the Hanover-Fierro stock, in the north-central part of the area, and the next largest is the Santa Rita stock, in which parts of the large open-pit mines are developed. The rock occurring in the 2 small stocks at Copper Flat and the 2 northeastward-trending dikes, about 1 mile to the east, differs from the ordinary granodiorite in that it carries very small amounts of ferromagnesian minerals.

Santa Rita stock.—The intrusive mass here called the Santa Rita stock invades Paleozoic and Mesozoic sediments as well as the quartz diorite porphyry of the Fort Bayard laccolith. Its relation to the laccolith could not have been determined at the surface, but in the southern mine pits dikes of the Santa Rita rock cutting the quartz diorite porphyry have been exposed. In the pits and underground mines the walls of the intrusion are nearly vertical, so that its structural relations are here those of a typical stock. Nevertheless, in its passage upward it deformed the sedimentary rocks, a feature that is discussed under "Structure" on page 43.

The normal character of the granodiorite at Santa Rita is well exhibited by material collected from the open mine pits at a point about 1,000 feet north from the office of the Chino Copper Co. Freshly broken surfaces show a porphyry comprising a dense gray groundmass, evenly distributed phenocrysts of a slightly greenish striated feldspar, and less regularly distributed prisms and flakes of dark-brown or nearly black mica. The feldspar and mica crystals show about the same range in size and have diameters of 2 to 6 millimeters. Thin sections examined under the microscope show a groundmass composed essentially of quartz and orthoclase in equidimensional interlocking grains. In different specimens the average size of grain ranges from 0.03 to 0.07 millimeter. The larger porphyritic crystals are andesine and biotite, besides which there are aggregates of secondary mica, representing altered phenocrysts of hornblende. There are occasional corroded crystals of quartz, apatite, and titanite, as much as 0.5 millimeter in diameter. Magnetite is rather abundant, and minute crystals of zircon and rutile are present. The groundmass contains about equal amounts of quartz and orthoclase. A careful estimate indicates that the proportions of andesine and orthoclase are respectively about 40 and 16 percent, so that the stock falls under the classification of granodiorite rather than quartz monzonite.

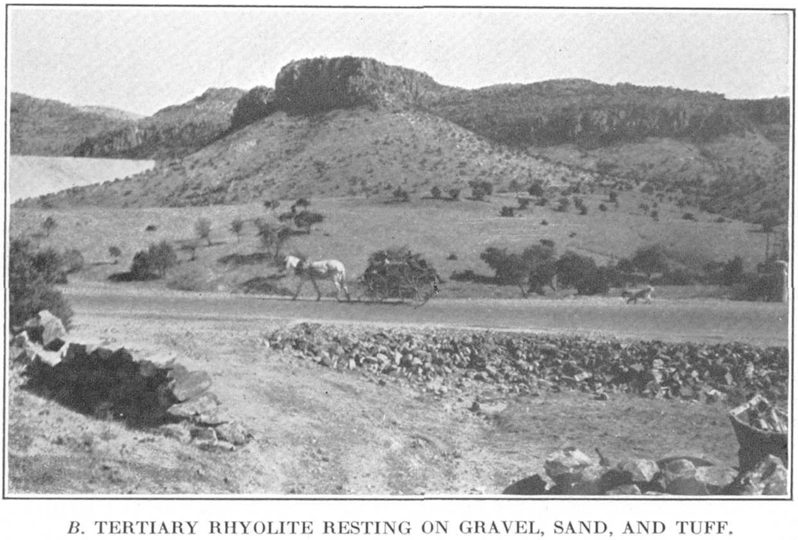
Hanover-Fierro stock.—The intrusive mass here called the Hanover-Fierro stock, from its occurrence in the Hanover Basin, is the largest of the granodiorite bodies of the district. It has a length of 2½ miles from north to south, and is from half a mile to 1 mile wide. The development of the topographic basin extending from Fierro to Hanover has resulted from the manner in which the rather coarse-grained granodiorite disintegrates under atmospheric influences, rendering it more easily eroded than the formations by which it is surrounded.

The walls of the intrusive are almost everywhere nearly vertical, and its general relations are clearly cross-breaking with respect to the sedimentary formations now exposed; but certain structural features of the surrounding invaded rocks suggest that in depth the



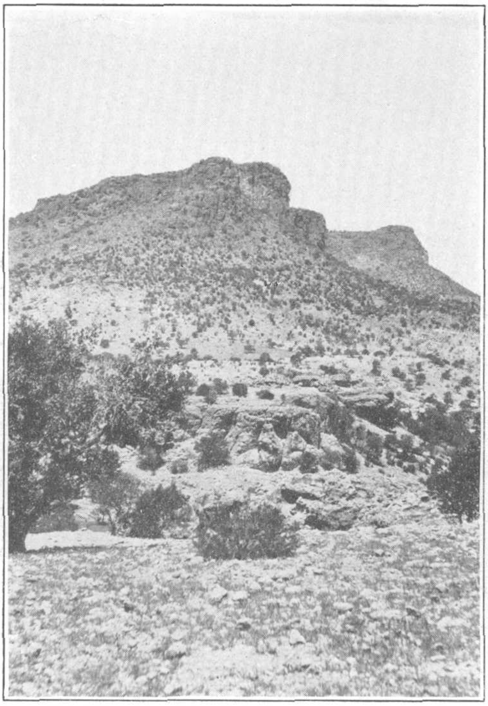
A. TERTIARY GRAVEL, SAND, AND TUFF BENEATH RHYOLITE LAVA, SOUTH SIDE OF BASIN SOUTHEAST OF LUCKY BILL SHAFT.

Photograph by Sidney Paige.



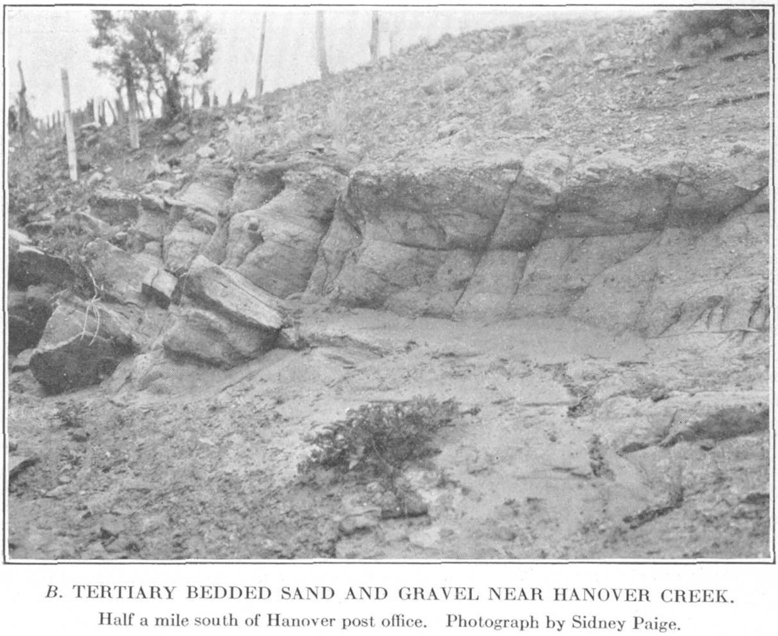
B. TERTIARY RHYOLITE RESTING ON GRAVEL, SAND, AND TUFF.

The tuff was deposited on porphyritic diorite. Edge of Chino dump on left. View looking southeast from highway 180. Photograph by Sidney Paige.



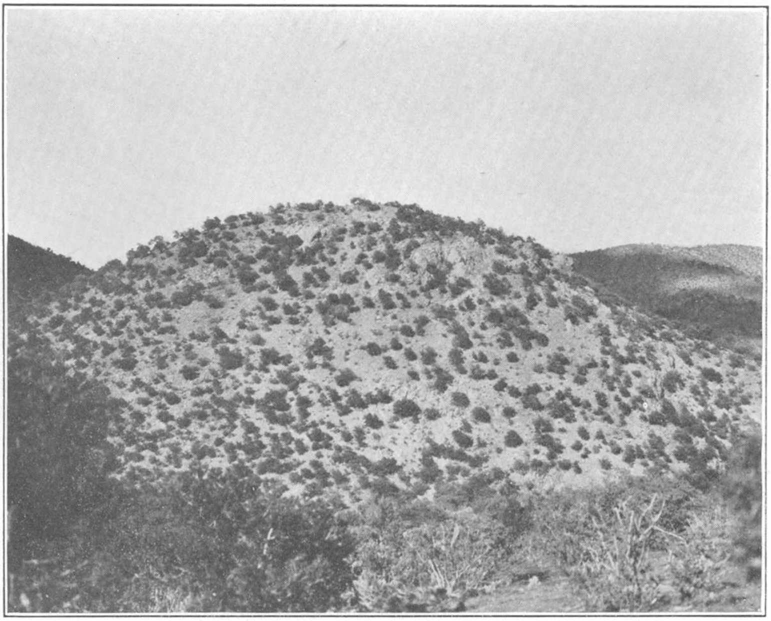
A. LAVA RANGE NEAR EAST EDGE OF SANTA RITA QUADRANGLE.

View looking southwest from point half a mile east of Santa Rita. Summits are of rhyolite, which rests on eroded diorite. Low cliffs in foreground are along Whitewater Creek. Photograph by Sidney Paige.



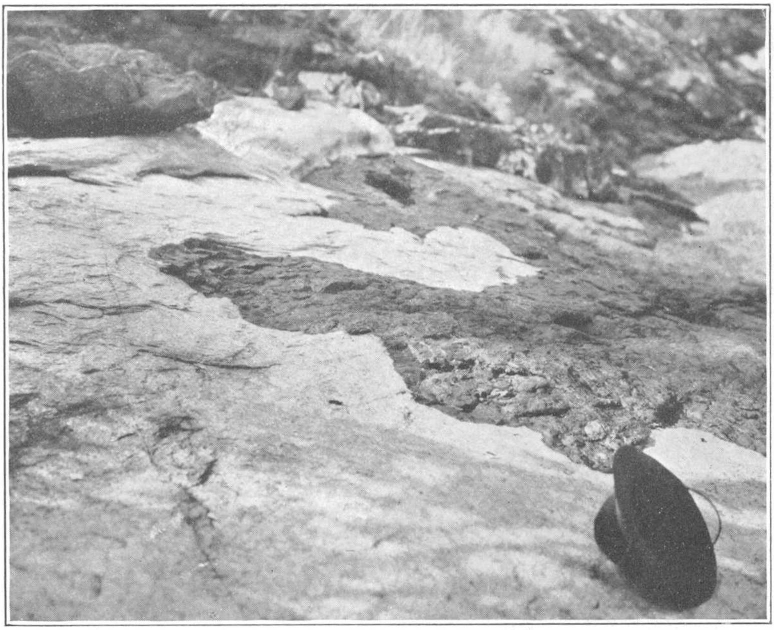
B. TERTIARY BEDDED SAND AND GRAVEL NEAR HANOVER CREEK.

Half a mile south of Hanover post office. Photograph by Sidney Paige.



A. BRECCIATED GRANODIORITE CUT BY NETWORK OF QUARTZ VEINS ALONG BARRINGER FAULT ZONE.

Photograph by Sidney Paige.



B. COLLOFORM MASSES OF SILICATE MINERALS REPLACING WHITE LIMESTONE OF LAKE VALLEY FORMATION.

In bed of Buckhorn Gulch west of Hanover post office. Photograph by Sidney Paige.

mass may have a laccolithic form. (See p. 45.) In different places the igneous rock may be seen in contact with all the Paleozoic formations, from the Bliss sandstone up to and including the Oswaldo formation, and on the north it invades the Colorado shale. Where erosion has exposed the Bliss and El Paso formations adjacent to its walls the strata usually show rather steep dips away from the stock, and on the east side these formations stand nearly on edge. The Paleozoic formations above the El Paso limestone are less steeply inclined, and their dips decrease with the distance from the stock, so that it is evident that the domal structure locally exhibited by the Paleozoic formations was produced as a result of the igneous intrusion.

The granodiorite of the Hanover stock is a light-gray, moderately coarse grained rock in which the principal minerals are white or greenish plagioclase, dark-green hornblende, and brown or nearly black biotite. Usually visible, though less readily recognized, are quartz, orthoclase, and magnetite. Most of the rock carries much less biotite than hornblende. In general the rock appears nearly even grained, but varieties that are markedly porphyritic occur, particularly toward the north end of the stock, and such material is very much like the rock of the Santa Rita stock.

Thin sections examined under the microscope show that the rock from the Hanover stock varies considerably in texture and composition, largely through differences in the proportions of groundmass and phenocrysts. Where the proportion of groundmass is small the texture is nearly granular, but with increasing proportions of groundmass the habit becomes distinctly porphyritic and the rock shows a rather close resemblance to that of the Santa Rita stock. The minerals occurring in well-formed crystals are plagioclase, hornblende, and biotite. The essential minerals of the groundmass are quartz and orthoclase, and accessory minerals comprise magnetite, apatite, titanite, and zircon. Plagioclase crystals measuring 6 by 10 millimeters occur, but most of them have maximum diameters of less than 3 millimeters. In different specimens the composition of the plagioclase ranges from albite-oligoclase to oligoclase-andesine. The hornblende, a green, slightly pleochroic variety, occurs both as anhedral grains and as prismatic crystals 3 millimeters in maximum length, having characteristic lozenge-shaped cross sections but lacking crystallographic terminations. Many of the hornblende crystals contain small, irregular inclusions of orthoclase. Some of the thin sections examined lack biotite, but where present this mineral occurs in well-formed but thin tabular crystals as much as 2 millimeters in diameter.

In specimens from different localities the groundmass consists of quartz and orthoclase, commonly in about equal amounts. They occur in irregular interlocking grains of approximately the same size. Thus the groundmass presents an even granular appearance, and the greater its amount the finer grained it is. As quartz and orthoclase occur only in the groundmass, it is evident that with the stated variations in the proportion of the groundmass there are considerable differences of mineral composition and that some of the rock may appropriately be called quartz diorite rather than granodiorite.

Stocks at Copper Flat.—Near the west side of the Santa Rita area, at Copper Flat, two small, closely spaced stocks of granodiorite porphyry break through the Oswaldo formation. The locality is about on the axis of the Fort Bayard anticline, and in the vicinity of the intrusions a slight domal structure has been imposed upon this broad fold. Excavations along the contacts show nearly vertical walls and therefore the stocklike form of the igneous bodies. Both stocks have rudely oval outlines; the smaller one, to the north, measures about 400 by 1,300 feet, and the larger one about 900 by 1,850 feet.

The granodiorite of the larger stock at Copper Flat is a light-gray fine-grained porphyry in which small phenocrysts of biotite, quartz, and colorless glassy feldspar are the only visible minerals. Thin sections of this rock examined under the microscope show numerous corroded quartz grains, a few well-formed quartz crystals, phenocrysts of albite-oligoclase ($Ab_{80}An_{20}$), small crystals of biotite, and a little apatite. The largest of the albite-oligoclase crystals are about 2 millimeters in diameter, but most of them measure around 1 millimeter. The corroded grains of quartz are mostly smaller than the feldspar phenocrysts, but many of the well-formed quartz crystals are of about the same size, and a few are larger than the feldspar crystals. The biotite, which is present in rather subordinate amounts, occurs as thin tabular crystals with maximum diameters of about 1 millimeter. The groundmass, constituting about one-third of the rock, is so fine-grained that the mineral components cannot be fully determined, but it contains both quartz and orthoclase.

Near the center of the larger stock, and probably constituting a later intrusion, there is a dikelike body of rock that differs from the porphyry of the main mass in that it contains large perfectly formed crystals of orthoclase and smaller ones of quartz. The orthoclase crystals are elongated parallel with the clino-axis so that their form is that of a nearly square prism. These prisms are commonly from 1.5 to 2 centimeters in diameter and from 3 to 4 centimeters long. The quartz crystals are doubly terminated prisms with axial diameters ranging from 1 to 1.6 centimeters.

Unaltered rock exposed near the northwest end of the smaller or northerly stock at Copper Flat is much like the porphyry of the larger stock, but it lacks quartz phenocrysts and has a slightly coarser texture. Thin sections examined under the miscroscope show a marked porphyritic habit due to phenocrysts of plagioclase, a large proportion of which have diameters near 2 millimeters. Small phenocrysts of biotite are also present. The groundmass contains both biotite and plagioclase but consists principally of equidimensional interlocking grains of quartz and orthoclase having average diameters of about 0.1 millimeter. The feldspar phenocrysts are essentially albite-oligoclase ($Ab_{80}An_{20}$), but through this mineral orthoclase occurs as irregularly distributed or reticulating inclusions that appear to be of later origin than the host.

The rock of the two dikes that cross the highway about a mile east of Copper Flat is a light-colored quartz-bearing porphyry that closely resembles the rock of the larger of the stocks described above. South of the road, where the western dike expands into a stock-like body, the limestones near the contact have been locally metamorphosed and charged with sulphide minerals. Copper ore has been mined at this locality, and about a quarter of a mile to the southwest a small deposit of galena occurs in limestone on the east side of the easterly dike.

Other granodiorite dikes.—Igneous intrusion did not cease with the emplacement of the granodiorite stocks at Santa Rita and Hanover. The fracturing that followed the cooling of these masses was accompanied by widespread intrusion of dikes, many of which are shown on the geologic map.

Of the dikes related to the granodiorite stocks, some may have been injected earlier than others, for in some places they cut mineralized veins, and in others they are cut by such veins; but these relations, on the other hand, may indicate a difference in age of the veins. In the zinc mines south of Hanover there are granodiorite dikes, the relations of which to the replacement deposits of sphalerite are somewhat in doubt. In the Groundhog mine, however, in the southern part of the area mapped, these dikes are earlier than the veins, as has been observed by Lasky. These dike intrusions may be regarded as episodes in a period of fracturing, hydrothermal metamorphism, and mineralization that followed the emplacement of the stocks.

Although it is recognized that some dikes may have been injected at the same time as the main stocks or in advance of them and may thus be regarded as offshoots of these masses, nowhere has such a relationship been proved. The two westernmost dikes in secs. 29 and 20, T. 17 S., R. 12 W., may be contemporaneous with the granodiorite intrusion of Copper Flat, for in composition and texture they are all much alike, but their interrelationship in time cannot be confidently established.

TERTIARY LAVAS

Tertiary lavas that are but parts of more extensive bodies occur on the north and south borders of the Santa Rita area. There is abundant presumptive and some direct evidence that these lavas once completely covered the Santa Rita area, and there are excellent structural reasons (see pp. 46–56) to explain their removal by erosion. Along the north border these lavas are almost wholly andesite or basalt, only two small outcrops of rhyolite appearing at the very base of the series; along the south border rhyolite flows at the base, aggregating 500 to 600 feet in thickness, are succeeded by a thin andesite flow and by higher rhyolites. These lavas dip southeastward at a rate of about 120 feet in a mile. (See pl. 5, *A*.)

The rhyolite south of Santa Rita, at a point about 2½ miles south of Cobre siding, is a light-bluish rough-surfaced rock with phenocrysts of glittering clear glassy feldspar, plainly visible quartz, and some biotite in an aphanitic groundmass. The rock contains abundant orthoclase, some unstriated oligoclase, and large crystals of ilmenite. The groundmass is a fine-grained aggregate of glass and feldspar. The rock may be classed as rhyolite, though it approaches quartz latite in composition.

In the tuff and gravel series near Hurley, southwest of the area mapped, is a thin flow, a light salmon-pink cellular rock of pumiceous aspect, that contains many fragmental inclusions as much as an inch long. In its glassy base are scattered unstriated feldspar phenocrysts of albite-oligoclase and a few flakes of biotite. Its groundmass contains numerous fibrous or spherulitic crystalline growths. Straight curved, and forking figures are present, made up of crystalline fibers set at right angles to parallel walls. These incipient growths are characteristic of western rhyolitic lavas.

The flow along the north border of the area is typically a dark rock of deep reddish hue, showing a great number of glittering feldspars of the same deep red color. The rock is distinctly porphyritic. Well-formed, relatively large, slender phenocrysts of labradorite and olivine, in well-developed crystals, and small grains of olivine are set in a microgranular groundmass. The groundmass, which forms more than half the body of the rock, contains rodlike crystals of feldspar and much finely granular pyroxene with abundant fine grains of magnetite. Flow structure is plainly indicated by the parallel arrangement of rodlike crystals.[30]

TERTIARY STOCKS AND DIKES

Within the Silver City quadrangle there are numerous stocks and dikes of postlava Tertiary age. Some of these stocks lie near but just outside the borders of the Santa Rita area. Within this area there are two igneous masses regarded as of Tertiary age and a great number of dikes that are placed in the same category. The two igneous masses are the small mass at Bull Hill, on the north side of the topographic basin that lies south of Hanover, and the irregular mass mapped near the southeast corner of the same basin.

The intrusive relations of the mass at Bull Hill are obscure. Faulting on both the north and south sides of the mass is a possibility, but the petrographic character of the rock is so similar to that of nearby dikes that cut the Tertiary sand and gravel of the basin that the Tertiary age of the stock may be affirmed with a high degree of confidence. The contacts of the mass are mapped as intrusive.

The irregular mass that invades the sedimentary rocks east and southeast of the basin is somewhat different in character from the Bull Hill rock, but the absence of metamorphic minerals within it, such as are characteristic of earlier dikes, and the fact that at one place it appears to invade sand and tuff of Tertiary age dates the mass with considerable assurance.

Dikes of Tertiary age are in most places readily distinguished by their petrographic aspect. Where such dikes cut the Tertiary sand and gravel of the Hanover Basin there can be no question of their late age. Dikes exactly similar petrographically have been mapped at many places. These dikes are characteristically later than the numerous granodiorite dikes, at some places cutting squarely across them; and they are characteristically free of the metamorphic effects, particularly the development of epidote, that everywhere characterize the earlier granodiorite dikes.

At most places the late dikes carry well-developed chilled selvages, and while earlier dikes are in a few places so marked the prevalence of this feature is far more characteristic of the Tertiary dikes. These later dikes are also prone to have tortuous intrusive contacts. They range in texture from rather fine grained porphyry to rocks which in a few places are comparatively coarse grained, particularly in the middle of the dike; but at such places the total absence of epidote serves to identify them.

[30] For a detailed description of the Tertiary lavas see Paige, Sidney, op. cit. (Silver City folio), pp. 9–10.

STRUCTURE

BROAD FEATURES

The folding and faulting that accompanied the invasion of Paleozoic and Mesozoic rocks by successive intrusions of quartz diorite porphyry and granodiorite and the Tertiary faulting that later affected the entire Santa Rita area have combined to produce complicated structure. Inasmuch as the structure disclosed today is the result of several definite movements widely separated in time, it is consistent to describe the folds and faults in the order of their occurrence, but a preliminary view of the broad structural features irrespective of the order of structural events seems desirable.

From the geology of the surrounding region as portrayed in the Silver City folio it is known that the Santa Rita area lies on the northeast limb of a shallow southeastward-trending syncline, the axis of which is about 4 miles southwest of Copper Flat. The syncline has an observed width of about 16 miles, from the crest of the Continental Divide, on the southwest, to Georgetown, on the northeast. It is modified by an anticlinal arch (named the Fort Bayard arch), the axis of which passes from northeast to southwest across the Santa Rita area, and this arch in turn is modified by a sharp transverse domelike anticline symmetrical with the topographic basin between Hanover and Fierro, by a more gentle dome having its crest north-northeast of Copper Flat, and by several folds on both flanks of the Fort Bayard arch. (See pls. 1 and 2.)

The existence of the Fort Bayard arch and the fact that its axis plunges gently to the southwest, or toward the keel of the broad syncline, is clearly revealed by strata of Beartooth quartzite that wrap around the Paleozoic formations so as to enclose them on three sides. These relations may be seen on plate 1, where also it may be observed that the simple upwarping of the arch is increased by strike or near-strike faults along both flanks. On the northwest side of the axis all the complementary displacement occurs along a single normal fault zone, which has been called the " Barringer fault zone ", whereas on the southeast side of the axis the total displacement by faulting is distributed stepwise along numerous breaks, most of which show downthrow in a direction that increases the effect of the anticlinal uplift. At the south end of the Hanover-Fierro stock, where a number of small faults trend north, this rule does not hold. (See pl. 2, cross section *B–B′*.) Although the broad structural features of the region may thus be simply stated, the structure in detail is more complex. Invasion by sills, laccoliths, stocks, and dikes at different periods, coupled with the faulting that accompanied them and the faulting that occurred later in postlava time, has greatly disturbed the orderly sequence of both Paleozoic and Mesozoic strata. To understand these disturbances, the effects of the successive invasions will be described in order.

FOLDS

Quartz diorite porphyry apparently invaded essentially flat-lying Paleozoic and Mesozoic rocks, though earlier gentle warping or tilting, whose effects are no longer distinguishable, may have occurred. The porphyry now appears in the form of sills in the Percha, Oswaldo, and Syrena formations and as sills, laccolithic bodies, and stocks in the Colorado shale. In the formations below the Beartooth quartzite the sills follow definite horizons with a marked degree of fidelity and are in marked contrast with the great laccolith in the Colorado shale, which shows strongly crosscutting relations at several localities and also encloses many large and small blocks of the shale. The observed difference with respect to regularity of form between the intrusive masses below and above the Beartooth quartzite is perhaps obviously related to the fact that the load to be lifted where the injections penetrated the Paleozoic formations was measurably greater than that above the Colorado shale.

The position of the feeders for the sills and laccoliths is not known, but it seems that there may be some beneath Hermosa Mountain and the igneous masses immediately to the north, and that another may be represented south of Santa Rita by the quartz diorite porphyry that clearly cuts across the Abo, Beartooth, and Colorado formations.

A substantial upwarp must have occurred above the Fort Bayard laccolith south of Santa Rita, for here the mass is still at least 1,000 feet thick in spite of erosion. In the southwestern part of the area also the violent effects of the invasion are to be seen. The base of the laccolith invaded the Colorado shale within a stratigraphic range of 280 feet. Three horizons appear to have been favorable—namely, the top of the Beartooth quartzite, the base of a 25-foot sandstone bed 80 feet above it, and the base of a second sandy series 200 feet above it. In places the laccolith crosscuts between these horizons, and here and there it has split so that it includes the beds between two of them. During the emplacement of the laccolith the invaded sediments were broken and pulled apart. Apparently numerous blocks of shale and sandstone were engulfed in the magma, although in many places it is difficult to distinguish between intrusive and fault contacts.

The Fort Bayard arch, although of simple structure in broad outline, is modified in detail by a number of minor anticlines and synclines, the axes of which are more or less parallel to the trend of the arch. Such folds, which in places are disturbed by later intrusions, especially north of the Barringer fault, suggest that compressional forces may have played a part in initiating this prominent structural feature, although it is recognized that the invasions of granodioritic magma, about to be described, were of such amplitude that a part of the doming may be assigned to their upward movement. In fact, it is reasonable to infer that here we have an example of magmatic movement impelled by compressional forces but resulting in effects that suggest local distention of the crust.

How long an interval elapsed between the invasion of the quartz diorite sills and the initiation of the granodiorite intrusions just referred to is not known, but it is to the movements related to or directly following these later intrusions that some of the larger folds and some of the faults of the area are due. There are within the area three centers where large masses of granodiorite appear and are obviously in a measure related to folding—between Hanover and Fierro, at Santa Rita, and at Copper Flat. Although it cannot be asserted that intrusion was contemporaneous at these centers, the weight of evidence favors the view that all three masses came to place at about the same time and that the subsurface volume of the magma is greater than would be suspected by casual inspection of surface outcrops.

The emplacement of the granodiorites was certainly accompanied by folding. Broad upwarping is conceived to have begun at an early stage of the invasion or before it—that is, before the magma had penetrated the Cambrian Bliss sandstone. At this stage the anticlinal arch was outlined and parallel folds within the arch initiated. The crest of the arch trends N. 60° E. from a point near Central, bisects the Hanover-Fierro intrusive mass, and corresponds with the crest of a fold in the quartz diorite sill near the edge of the area mapped. The arch plunges to the southwest, and its nose is clearly displayed at the surface by outcrops of Beartooth quartzite that encircle the Paleozoic formations. (See pls. 1 and 2, section *A–A′*.) Superimposed upon the Fort Bayard arch are two transverse anticlinal folds, the more prominent of which is related to the Hanover-Fierro mass of granodiorite. The other, lying west and southwest of Humboldt Mountain, is presumed to be related to a buried mass that connects beneath the surface with the granodiorite of Copper Flat. Between these transverse anticlinal folds there is a synclinal depression, along which two synclines indent the opposite limbs of the major arch but fail to depress its crest appreciably.

The causal relation between intrusion and the transverse folding is clearly displayed by the structural features surrounding the Hanover-Fierro mass of granodiorite. This elongate intrusive mass broke through the pre-Cambrian basement and in the early stages of its advance assumed the form of a laccolith. An elongate symmetrical dome was formed, the position of which has been established by direct observation at the surface. The continued upward movement of the magma was not directed symmetrically with respect to this dome. As it violently forced its way through each successive higher formation, dragging along the sheared Bliss sandstone, moving upward and southward, the axis of the intrusion shifted toward the southwest as the magma was progressively deflected away from the southern nose of the ancient dome. (See pl. 1.) At a stage in its progress which apparently preceded the penetration of the Percha shale, two folds developed within the beds lying in advance of its path—one a synclinal downwarp adjacent to the magma, the other anticline immediately beyond it. The synclinal downwarp was initiated in response to a marked southwest dip on the flank of the ancient arch, a dip that must have been increased by the bulge that necessarily formed above the wedge of magma as it forced its way southwestward and upward. The anticline beyond the syncline was a typical pressure ridge. Because the invading mass was narrow these folds developed a sharply bow-shaped outline along its front. (See pl. 1.) As the intrusive mass continued its advance, it forced the inner limb of the syncline to a nearly vertical position, with local overturning, and finally broke through and nearly obliterated it. The contact of the granodiorite at the surface today suggests that the magma then rose at a steep angle upward and outward on the northern limb of the anticline or pressure ridge. The present cup-like form of the broken syncline is regarded as due in part to the merging of the bow-shaped folds with the dip slope of the ancient arch and in part to the circumstance that hydrostatic pressure within the magma was directed circumferentially. The roughly circular lobe that characterizes its south end supports this view. The entire history of the invasion as interpreted from field observations emphasizes the conclusion that local structural features were first formed in advance of the magma and later disrupted by its continued progress.

It is clear from a consideration of the eastward dips of the Beartooth quartzite and the Colorado shale on the southeastern border of the Santa Rita stock and the westward dip of the same formations west of the ore pits on Lee Hill (north of the railroad station), that the upward passage of the magma warped the overlying beds into a definite arch. This view is supported by the outward dip of the beds in the Colorado shale that border the intrusive mass at its southwest corner.

Related to the domelike anticlines just described are a number of downwarps. A mile and a half west of Fierro on the south side of the Barringer fault, there is a cuplike depression involving Cretaceous strata. This depression appears to occur at the northwest end of a synclinal axis that is marked at its southeast end by a broad, shallow embayment of Cretaceous strata indenting the otherwise regular boundary of the Fort Bayard arch southeast of Humboldt Mountain. This embayment is now obscured by numerous faults, as will be shown below. A smaller syncline occurs east of the Santa Rita stock. An anticline is found west of Lover's Lane (the northward-trending road half a mile west of Santa Rita station). Part of a small syncline is nearly surrounded by granodiorite at the north end of the Hanover-Fierro stock.

FAULTS

Within the Santa Rita area normal faults are widespread, but they are particularly well developed in the southern part of the area. Their structural significance is clarified by considering the fault pattern of a much larger area—the 1,000 square miles embraced in the Silver City quadrangle. The fault pattern displayed here may be resolved into two systems—faults that trend northwest and faults that trend northeast. There is abundant direct and considerable presumptive evidence to prove that these faults are of Tertiary (post-lava) age.

Many of the shorter, northeastward-trending faults, such as those so well displayed in the range near Silver City, the Little Burro Mountains, and Lone Mountain, may reasonably be regarded as subsidiary fractures related to master dislocations that trend northwest and are longitudinally disposed with respect to mountain axes. The rocks forming these mountains were dislocated along these master faults and tilted toward the east, and it is clear that this movement did not cease in Tertiary time but has continued, in places at least, well into the Quaternary, for faults of considerable throw displace Quaternary gravel, notably the master fault at Georgetown, near the east edge of the Silver City quadrangle, and the fault along the western border of the Little Burro Mountains, to the west.

Within the Santa Rita area, however, there are faults that do not displace the Tertiary lavas. They are older than the lava and in most places are more or less mineralized. It is therefore a matter of considerable structural importance to discriminate so far as possible between prelava and postlava faults and to recognize, where possible, postlava movement on ancient mineralized fault planes or along nearby parallel fractures.

Viewed broadly, the continuity of the Fort Bayard arch is modified on both flanks by faults that either roughly parallel its axis or, as in places on the south, penetrate the arch. To the east, at Georgetown, the arch is sharply terminated by a strong fracture on which there has been notable movement during Quaternary time. The combined effect of these movements was to raise the central portion of the arch with respect to its flanks, as will appear in the description that follows.

In the northern part of the area mapped there is but one strong fault or fault zone—the Barringer fault zone, which passes between Fierro and Hanover Mountain. This dislocation, as shown in the Silver City folio, has been traced for 5 miles from a point near Shingle Canyon, on the northeast, to a point 1½ miles north-northwest of Copper Flat. It is named for the late D. M. Barringer, M. E., in recognition of his sustained interest in geologic studies during many years of activity in the development of the properties of the Hanover-Bessemer Iron & Copper Co., some of which lie along its trace. The nearly straight or gently curving trace of this fault throughout much of its course indicates the relative steepness of its dip, 45° or more to the north. It is a normal fault with downthrow on the northwest side. It transects in striking fashion a number of preexisting folds and emphasizes the distinction both in time and in character between those movements that were brought about or accompanied by intrusion and resulted in folding and those that resulted in simple block displacement. The transected folds referred to appear on both sides of the fault, which lies well within the borders of the Fort Bayard arch. The ultimate northern extension of the arch, however, is partly destroyed by intrusion and partly concealed by overlap of Tertiary lavas. At the southwest end of the fault, on Ansones Creek, the Beartooth quartzite, which curves northeastward on the nose of the arch, is sharply cut off on the opposite side of the fault by Cretaceous sandstone (higher stratigraphically than the Beartooth quartzite), which abuts against it. The northwestward dip and northeasterly strike of the sandstone beds display clearly the dropped northern extension of the arch. A short distance farther east a local shallow synclinal depression appears on the north side of the fault. It is reasonable to suppose that this depression is related structurally to the larger cuplike depression, involving Beartooth quartzite and Colorado shale, that appears south of the fault and but a short distance farther east.

A second fold, an anticlinal nose north of the fault, borders the Hanover-Fierro stock and marks its northern limit. This fold plunges gently northwest. Beartooth quartzite is here exposed resting on the Abo redbeds, beneath which are beds of the Syrena formation faulted down against the Percha shale, which forms the south side of the fault. Almost adjoining this plunging anticline but south of the fault line is a sharp synclinal fold plunging toward the fault. Here Colorado shale on the north is faulted down against Percha shale and Lake Valley limestone invaded by the Hanover-Fierro stock on the south.

Another very minor synclinal downwarp appears on the south side of the fault opposite the mouth of the small stream immediately northeast of Hanover Mountain. Some structural significance may attach to this downwarp in view of the fact that Hanover Mountain is in general a synclinal feature with a northward plunge. Cretaceous beds northeast of Hanover Mountain, though much disturbed by faulting and by the intrusion of dikes, have general northeast strikes and northwest dips and therefore support the view that the Fort Bayard arch extended at least as far north as the present position of the Tertiary lavas.

The Barringer fault passes directly across the end of the Hanover-Fierro stock. Its path through the massive granodiorite is marked by intense shearing along numberless fracture planes, which are filled with an intricate network of anastomosing quartz veinlets (pl. 6, *A*) in places so abundant that only mere vestiges of the igneous texture of the granodiorite can be discerned. Abundant pyrite and appreciable quantities of gold were introduced with the quartz. The close relation of the fault to the Fort Bayard arch, which was formed before the intrusion of the granodiorite, suggests that the faulting also at least began before the intrusion, but, as shown on page 49, there is no direct evidence to support this suggestion; on the other hand, the displacement of the minor folds that were formed at essentially the same time as the intrusion shows that a considerable movement along the fault occurred after the intrusion and produced the openings along which silicification of the granodiorite took place. The exact course of the fault through the granodiorite, however, is not clearly defined, and for this reason it is generalized on the geologic map.

The fault emerges from the east side of the stock where Colorado shale on the north is faulted down against successive beds of Lake Valley limestone, Percha shale, and rocks stratigraphically higher in the section. It also transects a sill-like mass of diorite porphyry farther east. Near the north edge of the area mapped the fault divides, and Colorado shale is brought down against the Abo and Syrena formations, which in turn are faulted down against the Oswaldo formation. The Barringer fault transects massive magnetite ore bodies developed in the underground workings of the Hanover-Bessemer Iron & Copper Co., immediately west of the granodiorite contact. These relations are displayed on the mine maps of the company and were observed underground. The Barringer fault is here a fault zone rather than a single break, and steeply northward-dipping faults carrying considerable gouge sharply limit ore against barren ground. The magnetite ore bodies in this zone are merely dislocated fragments of bedded replacement deposits related in origin to the early stages of granodiorite intrusion. In this general locality it has been impracticable to separate the formations, and those within the fault zone are mapped as undifferentiated.

The gentle deflection of the Barringer fault plane reflected in its curve around the south end of the Hermosa Mountain mass of diorite porphyry and in its equally gentle curve in the opposite direction as it approaches and finally transects the north end of the Hanover-Fierro stock is regarded as supporting the view that both igneous masses were rigid bodies before the initiation of faulting at this place.

In the features that have just been described there is evidence to support the view that horizontal as well as vertical movement has played a part in the displacement along the Barringer fault zone. The relative horizontal movement indicated was from east to west on the north side of the fault and may have been as much as 1,500 feet, though this figure is offered more as a suggestion than as a determined fact. In view of the fact that both north and south of the fault the terrane was folded and invaded by igneous rocks prior to the faulting, it is difficult to estimate the vertical throw precisely, for the apparent throw under such conditions is no true measure of the actual displacement and will vary from place to place. The throw of the Barringer fault is probably not less than 350 feet but may be more.

To fix the time at which movement began on the Barringer fault or the time after which movement ceased is not a simple problem. There is some direct evidence to support the view that movement began after the consolidation of the granodiorite stock, and no positive evidence to the contrary. And there is indirect evidence to support the view that post-lava movement may have occurred. This indirect evidence lies in part in the fact that the Barringer fault appears to be but one of a group of faults, many of which clearly cut the lavas, the only difference being that the nearby lavas may have been recently stripped from above the Barringer fault; and in part in the fact that the Barringer fault zone includes toward the northeast strong parallel fractures that are not mineralized. At a point 1½ miles northeast of the area mapped the Barringer fault is cut off by a master fault on which there has been even very recent movement. It is reasonable to suppose that in such major adjustments of the crust sympathetic movement occurred along the Barringer zone.

Faulting along the southern flank of the Fort Bayard arch did not follow a single fault zone, as on the north. On the contrary the displacement of the arch was effected through a number of normal faults of northeasterly to northerly trend, and for this reason the folds that antedated the faulting are not so clearly displayed. Nevertheless, the relics of these folds may be observed, and there are many facts of observation to support the belief that the same structural forces that molded the northern flank of the arch were effective here.

When the fault pattern along the south flank of the arch is studied on the geologic map (pl. 1) several striking relations appear. Notable first is the prevalence of faults that dip toward the southeast, a direction opposite to that displayed along the Barringer fault, on the north flank. Also noteworthy is the dropped block of Tertiary sand and gravel south of Hanover. Notwithstanding the fact that there are a number of faults that dip to the west or northwest, and few of these appear to be of large displacement, the general effect of the faulting has been to depress the south flank of the arch with respect to its axial portion. This relation is emphasized if account is taken of a strong fault which lies east of the Santa Rita area and can be traced for many miles, and which, as will be shown later, probably displaces rocks within the area.

The position of the down-faulted block of Tertiary sand and gravel south of Hanover deserves special consideration. It is doubtful if this remnant could have escaped erosion had post-lava faulting not occurred. Although there can be but little doubt that the lava series once extended over the entire region under discussion, it is reasonable to suppose that on the Fort Bayard arch the series was somewhat thinner than at other places to the north and south; and that after the faulting the arch stood even higher than before, in relation to the terrane to the north and south. Normally, therefore, it would be expected that the series of lavas would be removed first from the higher terrane. And apparently this has occurred, for in no other place in the central area are representatives of the lava series to be found. Some explanation is due, therefore, for the preservation of these particular outcrops of the basal formation of the lava series, and a reasonable explanation appears in the fact that these beds (see pl. 1) are surrounded on four sides by normal post-lava faults.

The general fault pattern under discussion includes faults within the bordering Tertiary lavas to the south and thus invites special attention, for here it is possible in places to distinguish definitely between post-lava and pre-lava movement. Faults that are clearly of post-lava age will be described first; those that may have a component of post-lava faulting and those that appear to be definitely pre-lava will be considered together.

Of the several faults that clearly displace the lava series, three are notable breaks. The largest post-lava fault is known as the Groundhog fault (from the Groundhog claim, which it traverses). This normal fault lies about half a mile southeast of Hanover Junction, trends in general N. 45° E., and dips about 55° E. Rhyolite on its east side is faulted down against the basal sand, gravel, and tuff of the lava series. The throw near the Groundhog shaft is about 180 feet, but there is some basis for the opinion that this displacement diminishes gradually toward the north. Efforts to trace this fault northeastward from Whitewater Creek have not been successful, first, because both walls are here in quartz diorite porphyry, and, second, because late movement that reopens older mineralized fractures is difficult to recognize. In line with the projected trace of the fault, however, a definite shear zone certainly occurs, and it is along this zone that the effects of the fault probably extend within 1,000 feet of the Ivanhoe shaft, if not farther, to join what is known as the Copper Glance fault (pp. 54–55).

A second post-lava fault lies about 700 feet southeast of Hanover Junction, also trends northeast, and dips to the east. It brings Tertiary gravel and sand on the east down against quartz diorite porphyry on the west. This fault is directed toward an area of quartz diorite porphyry in which mineralized fractures of pre-lava age trend east-northeast, and it is reasonable to suppose that any post-lava movement was absorbed on these older openings. The fracture certainly cannot be traced across a group of such veins that lie about half a mile north of Whitewater Creek.

A third fault that cuts the Tertiary lavas crosses Whitewater Creek about a mile southwest of Hanover Junction. This normal fault trends north-northeast, dips to the east, and brings the Tertiary gravel, sand, and tuff series down on the east against quartz diorite porphyry. It might be expected to pass near the east side of a block of intricately faulted Cretaceous strata to the north, but it may or may not extend that far north.

Another fault on which post-lava movement can be recognized marks the western boundary of the down-faulted block of Tertiary sand and gravel south of Hanover and may be traced 2 miles to the southwest, where it appears to fork and die out within an intrusive sill of quartz diorite porphyry and within Cretaceous shale. This normal fault dips about 80° E. and is remarkable for the clean-cut break that it displays—in fact, it is called the "Mirror fault" from the highly polished surfaces that may be observed in the Blackhawk or Combination mine workings, where metamorphosed Syrena limestone on the east side of the fault is brought down against the metamorphosed Oswaldo limestone on the west. It is estimated that at the Combination mine the throw of this fault is about 400 feet and that it diminishes gradually toward the southwest.

Three faults remain to be described that are clearly of post-lava age. These faults bound the dropped block of Tertiary sand and gravel south of Hanover on its north, south, and east sides. The eastern and southern faults can be traced without difficulty. The eastern fault for much of its course coincides with the west side of a dike that is regarded as younger than the fault. Near the fault the dips of bedded sand and gravel that strike N. 50° W. may be observed to steepen gradually from 45° to vertical as the fault is approached and reached. The southern fault is clearly marked by the sharp contact of sand, gravel, and breccia against Cretaceous shale or diorite porphyry. This fault curves northwestward and joins the Mirror fault on the west side of the basin. On the north side there are two faults with a general northeast trend connected by a northward trending fault lying west of the latite porphyry of Bull Hill.

At the road crossing of Hanover Creek a dike of latite porphyry is brecciated, but it is not apparent whether the brecciation is due to its mode of intrusion or to later movement.

On several faults that remain to be described it cannot be affirmed that there has been post-lava movement, though there may have been; and there are others on which there has almost certainly been little, if any, post-lava movement. These faults are so interrelated structurally that evidence as to their age will be presented as the faults are described. They do not fall into separate groups.

The block that lies southeast of the Mirror fault is limited on the southeast by a system of subparallel faults that have been named the Hobo fault zone, from the Hobo mining claim, which is about 3,000 feet southeast of the Combination shaft. The general course of the fault system is somewhat more northerly than that of the Mirror fault, the average direction being about N. 30° E. Through the greater part of the zone there are two prominent faults from which spurs diverge at a narrow angle toward the west, as the observer travels northeast. Within the fault zone the displacement is stepwise, the downthrow, with one minor exception, being on the southeast. From observations at the surface the dips of all these faults are steep toward the southeast. The combined displacement within the zone is probably about 500 feet. This estimate is fairly acceptable in the vicinity of the Combination mine but is subject to correction farther south, where the fault zone is flanked by a wedge-shaped graben, or down-faulted block, limited on the southeast by a readily recognized fault that roughly parallels Hanover Creek for nearly 3,000 feet and dips steeply to the southwest. From relations observed to the east, south, and west, it is apparent that a sill of porphyry occurs within this down-faulted block, but because the thickness of the sill is not known it is impossible to make a definite estimate of the displacement along this fault: it may be as much as 500 feet. The principal faulting along the Hobo zone is believed to have been initiated prior to granodiorite intrusion. This belief is based on a study of the complex system of mineralized fractures in the southwestern part of the area mapped, which indicates that this whole section was subjected to intricate deformation prior to the period of metamorphism and mineralization that followed the emplacement of the granodiorite stocks at Hanover and Santa Rita.

Within areas occupied by the Fort Bayard porphyry laccolith it is impossible to determine whether there has been displacement along any particular fracture, but where the Colorado shale is present it is possible to determine that faulting has occurred at least along some of the fractures. Such faulting may be demonstrated in many localities between Gold Gulch and the southwest corner of the area mapped, where the belt of Colorado shale is intricately broken and where most of the fractures show the effects of strong mineralization. Along most of these faults the downthrown block is on the southeast. Most of the prominent breaks trend about N. 40° E., but a few have more easterly courses.

A marked zone of fracturing occurs along or near the southeast edge of the shale belt from the south edge of the area to Gold Gulch and beyond. Here the displacement is also downward on the southeast side, but, because the thickness of the porphyry sill is not known and because its position in the Colorado shale has not been determined, the amount of displacement cannot be estimated with confidence. The post-lava fault that enters the area where the Atchison, Topeka & Santa Fe Railway track crosses the southern boundary is indicated by the local displacement of the quartz diorite porphyry and the basal gravel of Tertiary age. Although it is obvious that this break must continue toward the north, its position has not been located. In fact, it is possible that such movement may have occurred along old faults far to the north and even along the Hobo fault zone.

The Copper Glance fault is named after the Copper Glance mining claim, which lies north of Highway 180, about 1 mile northeast of Hanover Junction. This fault has been traced for a distance of about 3,000 feet. In the vicinity of the Copper Glance shaft the course is about S. 70° W. It follows about this course to a point 500 feet toward the southwest, where it assumes a nearly east-west course. Toward the east it can be traced for about 1,600 feet, to a point where it meets a well-marked and strongly mineralized fracture that can be traced southwestward nearly to Hanover Creek, a distance of perhaps 1,800 feet. These two fractures mark the edge of a block that is downthrown south of the Copper Glance fault. In the vicinity of the Copper Glance shaft black shale that belongs near the base of the Colorado shale and lies under the Fort Bayard laccolith occurs on the north side of the break. Toward the west a body of shale which lies above the laccolith occurs on the downthrown side. This relation indicates that the displacement could be measured if the thickness of the laccolith were known. Evidence in regard to the age of the fault is seen first in the fact that it is strongly mineralized and second in the fact that it is crossed by several dikes of granodiorite porphyry that are regarded as contemporaneous with the premineral dikes in the Ivanhoe, Groundhog, and San Jose mines. To the east of the Copper Glance shaft the fault can be traced to a point north of the Ivanhoe no. 1 shaft, where Beartooth quartzite appears on the north side and the porphyry of the laccolith on the south side. Beyond this point the break follows a dike of granodiorite about 150 feet wide, with exposures of metamorphosed Syrena limestone on the northwest side and of Colorado shale on the southeast side. The dike can be traced to the southwest across the Clara Barton and Ivanhoe claims, the point of divergence being about 1,200 feet southwest of the Ninety shaft. The single dike that continues toward the northeast is about 100 feet wide where exposed along the highway near the Ninety shaft. From this place it can be traced for a distance of about 300 feet, beyond which it is not exposed. In a small ravine just north of the common corner of the Ninety and Star mining claims Syrena beds are exposed on the northwest side of the dike and sandstone of the Colorado shale on the southeast side. Northeast of this point the actual position of the fault cannot be determined for a distance of 2,400 feet, but Colorado beds are exposed along the west side of the valley and Syrena beds on the hill slope toward the northwest, and the existence of an important fault trending about N. 25° E. is obvious. (See pl. 2, section *E–E′*.) Observations on the Door Key claim suggest shearing along the north side of the dike and indicate the possibility of late faulting along this line that may be connected with a northern extension of the Groundhog fault. The apparent displacement is about 400 feet.

The Romero fault, named after the Romero mining claim, occurs northeast of the granodiorite stock at Santa Rita. This break is to be seen on the east wall of the open pit, where metamorphosed Abo limestone, Beartooth quartzite, and Colorado shale are exposed on one side and beds that belong to one of the Pennsylvanian formations on the other side. From the mine pit for a distance of about 600 feet the course of the fault is about N. 20° E. Farther northeast the course is about N. 53° E. The dip in the neighborhood of the open pit is about 45° ESE. As may be seen from the geologic map the formations in the downthrown block have been considerably warped, and as a result it is obvious that the amount of displacement at different points would show a considerable range, but because it has been impossible to recognize definite horizons in the northwest upthrown block the amount of displacement cannot be estimated. On the south side of the north pit and on the south side of the south pit post-ore shear zones have been noted in the projected trace of this fault and may represent its continuation to the south. The weight of evidence thus favors movement of postgranodiorite age on this fracture, though the data are not decisive. Inasmuch as the shear observed on the south wall of the north pit involves a late (post-lava) dike, post-lava movement on this break is also suggested, but in view of the fact that outcrops are obscured by slide and mine waste a decision on this point is reserved.

The Joy fault, named after the Joy mining claim, follows the same general course as the upper valley of Santa Rita Creek and has been traced from the edge of the area mapped toward the southwest for 9,000 feet. Northeast from the point of intersection with the Romero fault its general course is about N. 29° E., and south of this intersection it trends about S. 10° W. for 1,500 feet or so and then makes a sharp change to about S. 30° W. In the neighborhood of the Seven Hundred well the dip is about 70° NW. and the estimated displacement is 360 to 400 feet. (See pl. 2, cross section *B–B′*.) The full extent of the fault toward the south is not known, but the amount of displacement obviously decreases in that direction, because there is no evidence of any corresponding break across the Beartooth quartzite along the east side of the mine pits. Movement along this fault probably occurred before the period of metamorphism that followed the injection of the granodiorite stock at Santa Rita, but clear evidence to prove this suggestion has not been obtained. Northeast of the junction with the Romero fault the rocks on both sides of the Joy fault are comparatively free from the effects of metamorphism, but south of this junction an increasing amount of rock alteration is observed toward the south, which suggests that the fracture may have offered a free course for the circulation of solutions during the period of ore deposition that followed the granodiorite injection.

A notable fault trending N. 80° E. lies just outside of the Santa Rita area, east of the southern mine pits at Santa Rita. This fault, which is normal and dips to the south, can be traced southwestward from the east edge of the Silver City quadrangle to a point about 1,000 feet distant from the east edge of the Santa Rita area. From this point westward the prevalence of highly silicified and oxidized Cretaceous shale and porphyry obscures the surface relations, but on the east edge of the south mine pit three small normal faults (not mapped), downthrown to the south, can be seen to offset the base of the Cretaceous rocks. In view of the fact that in tracing the fault southwestward a splitting into three parts was noted, there is strong presumptive evidence that this fault breaks the granodiorite porphyry. Whether there has been post-lava movement along these fractures is undetermined.

The formations within the anticlinal fold that adjoins the Hanover stock on the south are broken by several faults, most of which have courses that do not depart 10° from north. (See pl. 2, cross section *D–D'*.) Some of these breaks are older than the ore deposits of this area, and others are younger. So far as noted, all the faults of this system dip steeply toward the west. Only one of these faults exhibits a displacement as much as 200 feet. Some of the faults of the system have offset the boundary between the granodiorite stock and the invaded sediments.

METAMORPHISM

The rocks around the Santa Rita and Hanover stocks, as well as parts of these intrusives themselves, are notably altered in appearance and composition. After the solidification of the stocks marked fracturing occurred within them and around their borders, and heated mineral-bearing aqueous solutions, taking advantage of the paths thus afforded, arose from the lower portions of the cooling magma and circulated freely through the fractured rocks. In general, fracturing appears to have been a necessary forerunner of pronounced metamorphism, particularly in the igneous rocks, for where there are no fractures the invading rocks are not greatly altered, but where fractures are present there is notable rock alteration. The intrusion of quartz diorite porphyry represented by the Fort Bayard laccolith and related sills appears, on the other hand, not to have been accompanied or closely followed by any noteworthy amount of metamorphism.

Metamorphic aureoles that surround the Santa Rita and Hanover stocks overlap and form an irregular zone of altered rocks a mile or more in width that extends from north to south nearly across the area mapped. A separate and smaller aureole surrounds the intrusive granodiorite at Copper Flat, and in the southwestern part of the area the results of rock alteration, though not general, are conspicuous along numerous northeastward-trending fractures.

Within large masses of igneous rock, such as the Fort Bayard laccolith, channels of circulation were furnished by countless fractures, but where sedimentary formations have been altered it appears that differences in the composition of strata, together with the attitude of the beds and the position of fractures, dikes, or sills, played an equally important part in directing the course of the solutions.

With respect to the Santa Rita area as a whole metamorphism appears partly to reflect original differences in the composition and temperature of the active solutions from time to time and from place to place. The varied effects of metamorphism are seen in the recrystallization of limestones, the development of silicate minerals in limestone and shale, the conversion of limestone into ores of iron and zinc, the sericitization and silicification of shale and sandstone, and generally in the widespread sericitization of both quartz diorite and granodiorite.

Two distinct types of alteration have affected the sills and laccoliths of quartz diorite porphyry. Everywhere this rock shows the effects of a slight alteration by the presence of epidote and calcite replacing original hornblende, but in the southern part of the area, especially in the vicinity of Santa Rita, this alteration was masked by a later and far more intense alteration characterized by abundant sericite, and this sericite alteration likewise affected to a large degree the later granodiorite intrusions at Santa Rita and Hanover.

All the sedimentary formations of the Santa Rita area appear in contact with the Hanover-Fierro stock, at one place or another, although only the lowermost beds of the Colorado shale are involved. Within a border zone 800 to 2,000 feet wide that surrounds the stock the invaded formations exhibit the effects of hydrothermal metamorphism in greater or less degree, and in several outlying localities, some of which are more than 4,000 feet from the contact, marked alteration is also to be observed. In general, however, the most striking effects are close to the contact. Here a large amount of magnetite ore represents replacement of the Bliss sandstone and the El Paso and Montoya limestones. In these formations replacement appears to have been accompanied by plastic deformation, as the normal thickness of the formations has been in places greatly reduced. The magnetite ore bodies are tabular masses that generally conform with the stratification of the rocks and alternate with layers of limestone within which serpentine and wollastonite have formed abundantly and garnet and epidote to a minor degree.

In most places the iron ore replaced only part of the El Paso and Montoya limestones, but along Union Hill, where the thickness of the group is very much reduced, the replacement extended up to and included the topmost member. The limestone between the ore zone and the base of the Percha shale has been changed to marble without the development of noteworthy amounts of silicate minerals. Calcareous beds in the lower part of the Percha formation have rather generally been changed to a porcelainlike material, and locally similar alteration products occur in the upper part of the formation; in places large amounts of epidote have been developed in these limy shales.

The hydrothermal alteration of the Oswaldo, Syrena, and Abo formations had no very definite relation to the proximity of the granodiorite masses. The metamorphosing solutions were guided in part by cross-breaking fractures, but to a large extent they followed strata underlying beds of impervious shale or sills of intrusive porphyry.

The most thorough-going metamorphism of the Oswaldo formation is to be observed around the borders of the Hanover lobe of the Hanover-Fierro stock. Here the shale at the base of the formation has very generally been converted into epidote rock and the limestone beds have been extensively silicified or converted into magnetite ore. All the altered materials carry sulphide minerals in more or less abundance.

The same sort of alteration continued toward the south as far as the Santa Rita stock and affected both the Oswaldo and Syrena formations. Immediately north of the Santa Rita stock, where the rocks dip gently toward the south, layers of limestone that belong in the upper part of the Oswaldo formation have been extensively replaced by magnetite. Near the Ironhead mine, where the Oswaldo formation appears on the south side of the Barringer fault, the rocks have been altered in the same manner as in the vicinity of Hanover, the basal shales being converted into epidote rock and the limestones being silicified and charged with magnetite and sulphide minerals.

Northeast of Fierro, in sec. 3, T. 16 S., R. 12 W., marbleization of limestone beds in the Oswaldo formation has occurred at several places. Alteration of the rocks to silicates is unusual, but limestone beds have been replaced by magnetite in the vicinity of strong northeast-southwest fractures; and in the SE¼ sec. 3 considerable bodies of magnetite have been formed by replacement of limestone beds in the lower part of the Oswaldo formation.

The rocks exposed in the immediate vicinity of the granodiorite of Copper Flat belong in the upper part of the Oswaldo formation. The metamorphic aureole surrounding the intrusive mass is from 100 to 700 feet wide but not definitely limited on its outer borders. There is an inner zone of garnet rock charged with magnetite and sulphides and an outer zone of marbleized limestone.

East of Santa Rita the black shales that occur as the basal member of the Colorado formation have been converted to a dense hornstone, but in the vicinity of the pits these beds have instead been greaty sericitized and charged with pyrite. The same sort of alteration has been imposed on the sandstone beds that lie stratigraphically above the black shale and on the Beartooth quartzite that lies below this shale, and it is also noted west of the Santa Rita mine pits on Lee Hill.

Within a zone about 800 feet wide and 3,000 feet long, extending in a northwesterly direction from the Treasure Vault shaft, there are areas where the Colorado formation and the quartz diorite porphyry are characterized by the presence of alunite, which represents a hydrothermal alteration probably superimposed upon an earlier sericite-pyrite alteration, evidently in Tertiary time, inasmuch as the latite porphyry stock at Bull Hill is affected by similar alteration.

The calcareous argillite of the Abo redbeds, overlain by the relatively impervious Beartooth quartzite, was particularly susceptible to alteration, as may be observed at Humboldt Mountain and on the high ridge north of Santa Rita. As a rule this formation is altered to dense hornstone, but in the ore pits at Santa Rita it has been converted to a mixture of pyrite, magnetite, and chlorite.

Hedenbergite and ilvaite, of somewhat sporadic occurrence, are usually found with zinc sulphide, characteristically in places somewhat more distant from the intrusive masses than garnet and epidote. Fine examples of replacement by hedenbergite may be seen in Buckhorn Gulch west of the Hanover mass of granodiorite (pl. 6, *B*).

While the sedimentary rocks were being replaced by oxides, sulphides, and silicates, the igneous rocks underwent somewhat different changes in response to the action of solutions that were presumably very similar in chemical make-up. In the igneous rocks, sericitization, with the deposition of abundant quartz (in places astonishing amounts) and iron and copper sulphide, was the dominant process.

It is apparent that hydrothermal alteration operated during a considerable period of time, beginning in the early stages of the emplacement of the stocks and certainly proceeding on a grand scale after fracturing had occurred and even after granodiorite dikes had invaded the stocks and the surrounding sediments. The facts that in places apophyses of essentially unaltered granodiorite cut massive replacement bodies of magnetite and that these apophyses are in turn cut by aplite dikes (the earliest manifestations of dike intrusion that followed the solidification of the magmas) strongly suggest that replacement of limestone by magnetite occurred at a very early stage. The alteration of later granodiorite dikes, shown by the almost universal occurrence of epidote and sericite and the local occurrence of pyrite, proves that the processes of alteration were long drawn out. The fact that in places, notably in the Groundhog mine, sulphide ore bodies cut cleanly across these granodiorite dikes supports this view.

GEOLOGIC HISTORY

The Santa Rita area is so small (about 35 square miles) that many facts throwing light on its geologic history and geomorphology must be sought in the larger area that surrounds it. The quotations that follow, from the Silver City folio, are directly applicable to the Santa Rita area and will lead naturally to a discussion of its geomorphology.

> The long period that preceded Cambrian deposition doubtless comprised many intervals of sedimentation, erosion, and disturbance, representing in all a longer time than that represented by all succeeding geologic history. Only the merest fragments of this history can be read in this area. The pre-Cambrian rocks are largely granites, in which are enmeshed the almost indistinguishable traces of a sedimentary record. A few small areas of quartzite and schist point to the existence of ancient seas. The metamorphosed and fragmentary character of these ancient sedimentary rocks shows that their history has been varied.
>
> There is abundant reason to believe that old mountain ranges existed in this region and that forces of erosion in the past even as today carried on their work of denudation. The character of the surface upon which the earliest Cambrian strata [Upper Cambrian Bliss sandstone] rest in this area serves to verify what has been observed at many other localities—namely, that a period of prolonged erosion and baseleveling preceded the subsidence of the pre-Cambrian land beneath the sea, forming a floor of moderate relief on which the Cambrian sands were deposited.
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> The nature of the basal Cambrian strata, which are composed of quartzose, limy, and glauconitic material, shows that at the time of their deposition the sea was gradually transgressing upon a land surface of moderate relief. It is probable that as the sea advanced, wave action reduced still further the Cambrian sediments, and the pre-Cambrian basement is in part a result of this action.
>
> The subsidence whose beginning is marked by these Cambrian beds endured for a long period. As the seas gradually grew deeper or as the shore line slowly transgressed landward, limy sediments gradually became more prevalent,

and finally they formed the only record of deposition. Though these seas were not deep they were probably extensive. Whether the interval of time indicated by differences in the fauna of the Bliss sandstone and that of the El Paso limestone includes a period when Cambrian beds were raised above sea level and subjected to erosion cannot yet be determined. Apparently there was a rather abrupt transition from the sandy limestone layers of the older formation to the more limy beds of the younger formation, but if there is an unconformity it has not been detected. The incursion of sandy layers in the upper part of the El Paso limestone marks the unsettling of a delicate balance of depth rather than any great uplift. The quartz sands found in this part of the Cambrian system may have been carried there by currents that swept across wide areas of shallow seas or may have been blown from neighboring beaches by violent winds, for limestone deposits may be formed close to the seashore provided great quantities of debris are not being contributed to the sea.

The record of Silurian time, with its fossiliferous and chert-bearing beds, shows that the conditions then were similar to those of the preceding period. The abrupt change, however, from Silurian limestone to Devonian shale suggests a fundamental difference in conditions of sedimentation. Though the bedding of the Silurian limestone and the Devonian shale seems to be concordant, there is reason to believe that the beginning of Devonian deposition was preceded by marked erosion in this southwestern area. At Bisbee, for example, as stated by Ransome,[a] Devonian beds rest upon Cambrian limestone; at Clifton, as shown by Lindgren, Devonian overlie Ordovician beds; and in the Silver City region Devonian rest upon Silurian beds. These facts and the sudden change in sedimentation marked by the deposition of Devonian shale on Silurian limestone point to decided irregularities in the Paleozoic sequence in this southwestern province, probably indicating a period of uplift and erosion.

The gradual change from shale to limestone observed at the top of the Percha shale indicates an uninterrupted period of deposition between Devonian and Carboniferous time and a decided clearing of the seas. The faunal changes are likewise noteworthy. The muddy waters in which the top of the Percha shale was laid down seemed especially adapted to Devonian forms, but when the waters became clearer they were no longer a suitable habitat for the Devonian fauna which, therefore, disappeared and Carboniferous forms became prevalent.

The oldest Carboniferous fossils are found in the Mississippian Lake Valley limestone and no indication of interruption by sedimentation is disclosed until the base of the Pennsylvanian beds is reached. Here the Oswaldo formation is introduced by 20 to 30 feet of shale, beneath which in many places is to be found a bed of white or pink chert from a few inches to 8 feet in thickness. These features are the only indications of a physical break in sedimentation, for throughout the Silver City region the beds above and below the break appear to lie in parallel position. These relations indicate that although emergence of the sea bottom may have taken place, no substantial warping occurred at this time in this region.

[a] Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Bisbee folio (no. 112), p. 12, 1904.

A somewhat similar stratigraphic relation is found where the Permian Abo redbeds rest on the Pennsylvanian Syrena formation; here no notable disconformity was observed.

The point has now been reached where, instead of picturing quiet Paleozoic seas, the imagination must depict the gradual emergence of a Mesozoic continent. No evidence is at hand to prove that the uplift was accompanied by notable structural disturbance. No certain pre-Cretaceous faults are recognized, nor has any folding been observed which might not be assigned to later periods. It must be assumed, therefore, that though the emergence was widespread, it took place in this area without other deformation than that of gentle warping and tilting. That the tilting was appreciable is shown by certain relations between the basal Cretaceous beds and the underlying Paleozoic rock. For example, the Beartooth quartzite shows a remarkably clean-cut flat surface at its base, suggesting a decided leveling of the underlying floor, its contact on the summit of the Little Burro Mountains being a notably flat surface. Now, as the basal Cretaceous beds were deposited on [Permian], Pennsylvanian, Mississippian, Devonian, Silurian, and pre-Cambrian rocks, one may infer that these old rocks were tilted during their uplift and eroded nearly to baselevel across their dipping beds.

The absence of Triassic or Jurassic strata beneath the Cretaceous sediments points either to the existence of a continent during those periods or to an even more prolonged period of denudation than has just been inferred.

The accumulation of Cretaceous sandstone, shale, and limy shale to a thickness of probably several thousand feet followed the subsidence of this eroded land surface. The quiet sedimentation, however, may have been interrupted by subaqueous outbursts of andesitic and allied volcanic rocks. The breccias of the andesite-diorite complex have here and there the appearance of sills, being both underlain and overlain by shale; but as the pyroclastic nature of the breccia precludes an intrusive origin, it is suggested that near the close of Cretaceous sedimentation, or after its close, volcanoes added their quota of material to the marine Cretaceous accumulations. The apparent sill-like relation observed may, however, be due to faulting.

There is abundant evidence of intense activity from this time on. Thousands of dikes cut both the Cretaceous shale and the breccias, indicating that the outbursts that furnished the pyroclastic accumulations were followed by continued long-extended fracturing of the strata and concomitant filling with igneous material. The great preponderance of this complex in the Cretaceous rocks suggests that a center of volcanic activity existed somewhere near or north of Pinos Altos, though there may have been subsidiary centers near the Little Burro Mountains.

The history of the region now enters upon a period notably different from the preceding long record of sedimentation. There is no evidence that the land was ever again beneath the sea, but there is conclusive evidence that no less than five stages of intrusion succeeded the one already described, and further that they were associated with notable structural dislocations.

The first of these intrusions is represented by quartz diorite porphyry, which now appears in the form of numerous sills in the Percha, Oswaldo, and Syrena formations and as sills or laccolithic masses and stocks in the Colorado formation. The position of the feeders for the sills and laccoliths is not known, but it seems possible that the Hermosa Mountain stock and the thick mass south of Santa Rita may represent such feeders. Considerable warping of the strata must have occurred above the Fort Bayard laccolith and above the Hermosa Mountain stock, with gentler warping in the beds overlying the thinner sills, and it is clear that these invasions were accompanied by more or less disruption of the invaded strata.

It is known that some time intervened between the invasions just described and the emplacement of the granodiorite masses at Hanover, Santa Rita, and Copper Flat, for these masses invade the quartz diorite porphyry.

The broad anticlinal upwarp, here named the Fort Bayard arch, on which there are numerous minor folds, was developed during this interval, evidently by compressional forces, and was essentially completed before the invasion of the granodiorite masses. This invasion was accompanied by folding transverse to the axis of the arch and was followed by fracturing on a great scale, faulting, the invasion of granodiorite dikes, and widespread hydrothermal metamorphism and the deposition of ores of iron, zinc, lead, and copper.

The principal movements along the Barringer fault and the prelava faults of the southern part of the area probably occurred at this time.

A prolonged period of erosion ensued. The cover was stripped from the granodiorite masses, an irregular topography was developed, and pre-lava enrichment of the zinc ores at Hanover and the copper ores at Santa Rita undoubtedly occurred.

At some time in the Tertiary widespread volcanism began, with violent explosions that spread coarse and fine volcanic debris over the uneven land surface. This material was redistributed by torrential rains to a considerable degree and eventually formed the gravel and finer sediments that are now exposed along the southern edge of the Santa Rita area and elsewhere. These sediments were covered by great sheets of rhyolitic or latitic lava that covered hills and valleys, obliterating the older landscape. After these eruptions there were floods of andesitic or basaltic lava, followed by rhyolitic lava. Local deposits of fine sand and tuff accumulated between these outbursts.

This volcanic period was followed by faulting, which apparently compensated for the vast transfer of lava from its underground reservoir to the surface and has been intermittently active ever since. During its earlier stages it was attended by the intrusion of stock-like masses and dikes of latitic rocks that cut the Tertiary lavas and all the older rocks, but none of these intrusive rocks have been found to cut the lavas within the Santa Rita area. After completion of the principal movements along these faults, the lavas and the tuff and gravel beneath them were eroded from the Fort Bayard arch, with the exception of the sand and gravel in the topographic basin south of Hanover, which were preserved by local downfaulting.

ORE DEPOSITS

The ore deposits of the Santa Rita area were formed during a period of mineralization that may have in part accompanied the early stages in the emplacement of the granodiorite stocks but in the main was later than the granodiorite. These masses and the invaded rocks around them, in consequence of forces that may reasonably be assigned to final upward movements of the cooling solid intrusives, were in many places intensely fractured. To the widespread hydrothermal alteration that immediately followed and that may be regarded as an end effect of the intrusions the ore deposits are in large measure due. Dikes of granodiorite porphyry invaded the stocks and the surrounding rocks about this time, but it is clear that mineralization both preceded and continued after the emplacement of these dikes. Thus fracturing, hydrothermal metamorphism, the intrusion of the dikes, and the deposition of the ores may all be regarded as episodes of an extended period of magmatic invasion.

All the ores were precipitated from heated aqueous solutions. Their mineralogic make-up, the place in which they were deposited, and the form that they assumed depended on the concentration, temperature, and pressure of the solutions and on the character of the rocks that were available to receive them. Inasmuch as a great variety of rocks, calcareous, argillaceous, and igneous, variously disposed, adjoin the stocks, and inasmuch as fracturing in places occurred at long distances from the intrusives, there resulted a variety of ore deposits—contact deposits, disseminated porphyry ores, and veins.

Sedimentary rocks, chiefly calcareous or magnesian, surround the Hanover-Fierro stock. During and after the intrusion high temperatures prevailed along the contacts, and solutions circulated freely. There formed in consequence around the intrusive mass a rude shell, varying in mineral make-up from place to place, made up of iron oxides, sulphides, and lime-magnesium-iron silicates.

CONTACT-METAMORPHIC DEPOSITS

IRON ORES

Historical sketch.—According to Kniffen,[32]

The mine of the Hanover-Bessemer Iron & Copper Co. at Fierra * * * is the only operating iron mine in the southwestern part of the United States

[32] Kniffen, L. M., Mining and engineering methods and costs of the Hanover-Bessemer Iron & Copper Co., Fierro, N. Mex.: U. S. Bur. Mines Information Cir. 6361, 1930.

[1930]. * * * Nearly all the iron ore is shipped to Pueblo, Colo., a distance of 694 miles, where it is smelted by the Colorado Fuel & Iron Co. The mine is not a large producer. * * * In recent years the annual shipments have amounted to about 200,000 tons. The property is noteworthy chiefly on account of this long transportation by rail and the economical methods that have been developed to make the operation profitable. * * * The large outcrops of magnetite attracted attention for many years, but the lack of transportation made them of no economic value. Soon after the railroad was brought to Silver City some "float" was shipped to Pueblo that had been hauled from Fierro by ox teams, on the return trip, after bringing supplies to Fort Bayard. The Hanover-Bessemer Iron Ore Association was organized in 1899, at which time the railroad was built to Fierro. * * * In 1914 the Hanover-Bessemer Iron & Copper Co. was incorporated, and a contract was made for the sale of the iron ore. A fine-grinding wet-concentration mill was built in 1916. A controlling interest was acquired by the United States Smelting & Refining & Mining Co. in 1919.

Geology.—On both sides of the Hanover-Fierro stock, in places where the contact of the igneous mass is parallel with the invaded strata, are commercially important deposits of magnetite which obviously have been formed by replacement. On the east side of the intrusive mass this condition persists throughout a distance of 6,000 feet; on the west side for about 5,000 feet. On both sides the formations stand at high angles, and from place to place there is strong evidence of plastic deformation of the limestones, as a result of which the El Paso limestone has suffered a reduction in thickness. The magnetite ores of high grade occur in the lower part of this formation, and in general it may be said that replacement ceased at a definite horizon, which is everywhere recognized because of the presence of serpentine. It is believed that the serpentine developed as a result of the metamorphism, and that the zone in which it occurs represents a chert horizon of the Silver City region. The Bliss sandstone also makes ore, but of a distinctly lower grade. Although the ore bodies follow the stratification in the main, there are a few places where veins in either border extended out into the limestone above the serpentine horizon.

It is a noteworthy fact that the magnetite deposits occurring in the lower Paleozoic section have replaced magnesian formations and that the principal silicates are wollastonite and serpentine, with minor amounts of garnet and epidote. On the east side of the intrusive mass the magnetite ores have followed the contact between the Bliss sandstone and the El Paso limestone, replacing both formations. The thickness of the ore averages about 40 feet but in places may be as great as 200 feet. Here and there alternate beds of unreplaced limestone occur; in general the ore exhibits a rude lenticularity. The Bliss sandstone merges upward by gradual increase in calcareous layers with the El Paso limestone, and no clear-cut boundary between the ores of the two formations is to be expected. On the west side of the intrusive mass the El Paso limestone is thin, either because of strike faults or because of plastic flowage. The ore zone occupies the full thickness of such of the Bliss sandstone as remains along the igneous contact and all of the El Paso formation up to and partly including the low-grade serpentinized chert layer. In a few places, notably on the west side of the granodiorite mass at the north end or the company's property, veinlike bodies of magnetite cut across the serpentine zone into the Montoya limestone, which lies stratigraphically above the El Paso limestone. Minable ore bodies have replaced the Fusselman and Montoya limestones just beneath the Percha shale.

Pyrite, chalcopyrite, and chalmersite are noteworthy constituents of the magnetite ores and are clearly of somewhat later date, as proved by their prevailing veinlike distribution through the massive magnetite. Sphalerite likewise occurs sporadically in the magnetite.

The average partial analysis of the concentrates shipped is as follows:

Fe	51.00	CaO	1.41
P	.058	MgO	13.38
SiO_2	7.28	Cu	.37
Mn	.72	S	.38
Al_2O_3	1.42		

Ores of magnetite occur also at the south end of the intrusive mass, near Hanover, where they have replaced nonmagnesian limestone of Pennsylvanian age. Here ore has been mined in past years for a thickness of 50 feet and over a distance of 3,000 feet along the contact. Exposures are not good except on the Cupola claim, directly south of Hanover station.

North of Santa Rita there is a considerable area where nonmagnesian limestones of the upper part of the Oswaldo formation have been converted into magnetite. In this locality the ore is not confined to the contact of the granodiorite but over a considerable area has replaced a certain layer of the Oswaldo formation. In the early days the ores were shipped for flux, and in 1931 20,000 tons was shipped to Pueblo, Colo.

ZINC ORES

The mines of the New Jersey Zinc Co. at Hanover, which have been worked more or less continuously since 1902, are credited with an output of 500,000 tons of sphalerite ore, having an average content of 15 percent zinc, and in addition considerable amounts of high-grade carbonate ore, most of which was produced prior to 1918. The ores were particularly desirable because they were essentially free of lead. An average analysis representing several thousand tons of mill heads is as follows:

Zn	17.49	MgO	1.81
Pb	.13	CO_2	3.37
Fe	6.19	S	10.19
Mn	.94	Insoluble	49.77
CaO	8.09		

The ore was milled at Hanover; the first mill was a magnetic concentrator, the later mill of the flotation type. The mines are south and west of the Hanover-Fierro intrusive mass, all within a zone of intense alteration, 800 to 1,500 feet wide, that adjoins the intrusive.

The typical ore bodies occur in the upper part of the Lake Valley limestone and are essentially confined to a massive limestone member about 120 feet thick, locally known as the "white crinoidal limestone." This member appears at the surface on the crest of a curving anticline which closely parallels the southern lobelike end of the intrusive mass on its west and south sides but which because of faulting is not continuous.

The ore bodies are typical replacement deposits in limestone—either upright tabular masses controlled by steeply inclined fractures, some of which are paralleled by granodiorite dikes, or rude blanketlike deposits developed especially within the upper part of the crinoidal limestone beneath a bed of highly metamorphosed shale, which constitutes the basal member of the Pennsylvanian Oswaldo formation. The blanketlike deposits on the west side of the intrusive mass reach a thickness of 120 feet and are of considerable extent. Most of the upright tabular ore bodies are found on the west side of the dikes which they accompany. The largest of these bodies was 120 feet high, more than 1,000 feet long, and 30 feet in maximum width.

The sphalerite in general is found in the outer part of the metamorphic aureole, associated with hedenbergite, ilvaite, and manganese-bearing calcite. Magnetite, on the other hand, is found next to the contact of the granodiorite, and in between the magnetite and the zinc ores are masses of garnet and epidote carrying disseminated sphalerite. The zinc ores contain greater proportions of lead as distance increases from the intrusive mass. Some of the ore bodies are jacketed by unusual amounts of galena. Fractures with northeast and north trends that traverse this terrane certainly acted in places as channels for ore-bearing solutions, but there are reasons for believing that replacement of the limestone proceeded quite as readily by the passage of aqueous heated solutions with considerable freedom through large masses of marbleized limestone, for it was observed that the replacement of the limestone either by hedenbergite, garnet, or sphalerite proceeded in very much the same way. Places may be observed where solid hedenbergite or garnet has completely replaced limestone along sinuous lines of knifelike sharpness, on one side of which appears solid silicate, and on the other pure marbleized limestone. In places mixtures of garnet and hedenbergite, one or the other, or both, with sphalerite are too low in grade to constitute zinc ore. Between these ore bodies and the granodiorite contact garnetized limestone usually prevails, and the boundary of the ore is indefinite against the garnetized rock. In general, though not everywhere, the ore grades through lean material to wall rock.

The position of the zinc ore bodies south and southwest of the granodiorite stock appears to have been controlled by preexisting faults or dikes. Here, in striking contrast to the blanket ores that lie west of the granodiorite contact and are continuous for long distances along the strike of the crinoidal limestone, the ore bodies are alined along faults and dikes. Their longer axes are invariably normal to the granodiorite contact and roughly parallel either faults or dikes. Here, as on the west side of the intrusive, the crinoidal limestone is the host rock, and here also the overlying shale has acted as a barrier to the upward movement of solutions, for the ore terminates abruptly against it and fades away laterally beneath it as distance increases from the controlling steeply inclined fissure or dike.

Of six ore bodies associated with such faults and dikes only two are reported as carrying minor amounts of ore on the east side of the dike.[33] Accumulation appears to have been directed along the west side of the dikes. Such a structural relation is strong presumptive evidence that the granodiorite dikes were earlier than the ore, but of itself it cannot be offered as conclusive evidence.

That pre-ore fractures or dikes directed the movement of solutions is hardly open to question, but it is possible that pre-ore faults alone effected the results observed, that the dikes were intruded somewhat later along or near the existing fractures, and that post-ore movement has still later occurred along the ancient openings; for there is ample evidence of post-ore faulting, both on the surface and in the mines.

Inasmuch as sphalerite ore is not found in the dikes, though these dikes are epidotized and sericitized, the senior writer is inclined to the view that the dikes invaded the ore and are thus later, and that the occurrence of ore principally on the west side of the dikes is

[33] Schmitt, Harrison, oral communication.

explained by some phenomenon not connected with the dikes but with the fractures that are presumed to have controlled ore deposition.

Zinc ores are not confined to the Lake Valley limestone but have been mined from deposits in the overlying Oswaldo and Syrena formations, of Pennsylvanian age, on the properties of the Peru Mining Co., east of Hanover, and of the Blackhawk Mining Co., about a mile south of Hanover.

ORES OF DISSEMINATED CHALCOCITE AT SANTA RITA

At Santa Rita a granodiorite porphyry stock invades Paleozoic and Mesozoic sediments and a mass of quartz diorite porphyry. The southern boundary of the granodiorite where it cuts the quartz diorite porphyry is obscure, for widespread hydrothermal metamorphism has destroyed many of the distinguishing characteristics of the invading and invaded rocks, both igneous and sedimentary. The granodiorite where unaltered is similar petrographically to the larger mass at Hanover and also to the smaller masses at Copper Flat, though the latter are somewhat finer grained. The thorough alteration of limestone to silicates, shown at the surface between Hanover and Santa Rita, suggests that the two granodiorites are connected at moderate depth.

The quartz diorite porphyry is regarded as part of the Fort Bayard laccolith. The crosscutting relations that this rock displays south of Santa Rita where it breaks across the Abo, Beartooth, and Colorado formations suggests that here or somewhat farther to the south beneath the lavas may be the position where the magma rose through the basement rocks. Churn drilling indicates that the quartz diorite porphyry is at least 945 feet thick. If the intense alteration to which the rock has been subjected is taken into account, and also the fact that many large intrusions vary in minor details of mineral composition, there is more to support the view that this rock is part of the Fort Bayard laccolith than the view that a third intrusive mass is present.

The emplacement of the granodiorite occurred in late Cretaceous or early Tertiary time. Owing perhaps to waning upward movements of intrusion, the borders of the solidifying mass, as well as the adjoining wall rocks, were intensely fractured. There ensued a period of thorough hydrothermal metamorphism, with sulphide mineralization and dike intrusion. It is noteworthy that where sulphides are abundant there has been intense fracturing, but that where fracturing was relatively slight mineralization occurs to only a minor degree. The ringlike disposition of the ore bodies at Santa

Rita strikingly illustrates this relation, for the core of relatively unfractured granodiorite is relatively unmineralized. (See fig. 1.)

If the map of the ore bodies illustrated in figure 1 is superimposed on a geologic map prepared before excavation by steam shovels had appreciably progressed, it becomes clear that much ore was formed in the sedimentary rocks adjoining the granodiorite mass. This is

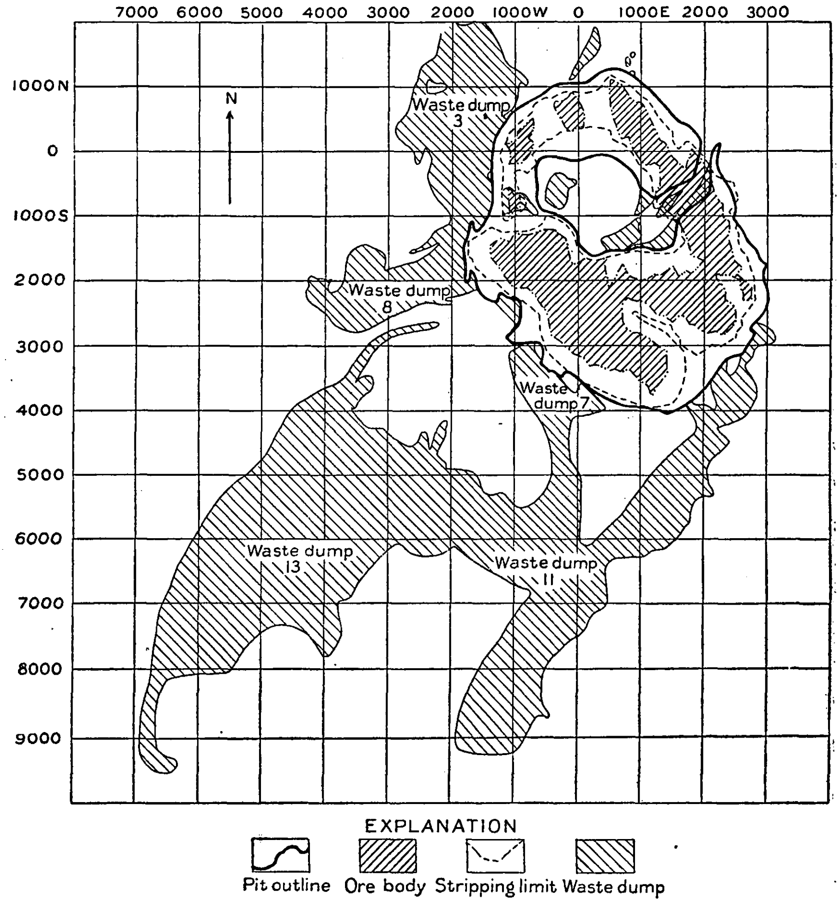

FIGURE 1.—Ore body, stripping limits, pits, and waste dumps at Chino mines. After Thorne, H. A., Mining practice at Chino mines, Nevada Consolidated Copper Co., Santa Rita, N. Mex.: U. S. Bur. Mines Information Circ. 6412, fig. 5, 1931.

particularly true with respect to the ore body on the east side of the stock, where Abo limestone, Beartooth quartzite, and Colorado shale all carried ore. Abo limestone and quartz diorite porphyry carried ore at the south end, and considerable Colorado shale was excavated on the southwest side. The ore bodies along the northwest border lie next to the contact. These facts serve to emphasize the conclusion that circulating solutions sought out those places where fracturing was highly developed—namely, at the borders of the intrusion—and made ore irrespective of the host rock.

The granodiorite deformed the sedimentary rocks that it invaded. At the northeast side the resulting dip is very local, for the regional dip of the Syrena and Oswaldo formations is southward, toward the stock. The axis of the anticline indicated by these dips trends northwest. A short distance to the east a synclinal depression trends in the same direction. These folds and comparable folds that have been recognized farther to the west are regarded as due in part to the intrusion of magma and quite distinct in time and origin from the prominent faults that are regarded as of post-granodiorite age and as having suffered, probably, some movement in post-lava time (Tertiary).

The value of the ore bodies at Santa Rita is due directly and almost entirely to enrichment. Primary mineralization by pyrite and chalcopyrite accompanied the silicification and sericitization of the fractured rocks. This process was carried to great lengths. Colorado shale was altered to a porcelainlike siliceous rock that can be distinguished from altered porphyry only by painstaking examination with a hand lens. Quartz diorite porphyry in its altered facies is distinguished with difficulty from altered granodiorite.

The minerals that have given and still give value to the deposits, particularly in the upper zone, are malachite, azurite, chrysocolla, cuprite, and native copper, but chalcocite and chalcocite-coated pyrite are the most abundant minerals. These are generally disseminated through the rocks and in small seams and stringers. Quartz, sericite, halloysite, and kaolin are common gangue minerals.

It is well established from regional studies that the enrichment beginning in pre-lava time was interrupted by floods of Tertiary lava and was resumed after the removal of the lavas by erosion in Quaternary time. It was in this connection that post-lava faulting played so important a part, producing the horstlike uplift, already described, of the area north of Santa Rita. This uplift brought about the erosion of the lavas from above the Hanover and Santa Rita intrusive stocks and initiated a second period of enrichment.

The thickness of the overburden (above the ore bodies) is extremely variable. There is none over the northwestern and northeastern portions of the ore bodies and in small areas elsewhere, but it reaches a maximum of about 150 feet over the southern portion. The contours of the top and bottom of the ore are very irregular. In the main part of the ore bodies the thickness of the ore reaches 600 feet, but along the margins it decreases to 300 feet and less. None of the ore bodies have been fully delimited by drilling, either vertically or horizontally.

VEINS

The fracturing and hydrothermal metamorphism that followed the emplacement of the granodiorite stocks was not confined to the immediate vicinity of the large masses now exposed at the surface (Hanover and Santa Rita). In the southwestern part of the Santa Rita area and extending to Central the quartz diorite porphyry and associated sediments are traversed by numerous mineralized fractures that trend northeast. As a group they are characterized by wall-rock alteration and by minerals that strongly suggest an origin related to the granodiorite intrusions; and the presence of numerous granodiorite dikes supports this view. It is not unreasonable to suppose that in depth there are larger masses of which the dikes may be apophyses.

Although this region has been prospected for many years, only a few of the veins have been worked with profit. Of these the most productive occur near and east of Hanover Junction. Here a mineralized fracture zone trending northeast has been developed throughout a length of about 4,000 feet. The first development was near the north end of the zone on the San Jose claim, located in 1875, from which copper, lead, and silver were produced, for the most part prior to 1895. Work on the Lucky Bill claim, at the south end of the zone, began about 1900, when lead carbonate and vanadate ores were discovered. The total production of this claim amounted to several hundred thousand dollars.

Lasky [34] says:

Due to the fact that the outcrop on the Groundhog claim, which adjoins the San José on the southwest, was mostly covered with rock debris and the exposed parts of the vein were barren quartz, this claim was not located until 1900.

The net smelter returns of shipments from the Groundhog up to 1917 were about $50,000, representing about 2,000 tons, derived from lead-copper ores encountered about 100 feet below the surface at the south end of the claim. The mine was sold in 1917, and from then until February 1920, when shipments ceased due to temporary closing of the smelters, the property produced 6,430 tons of lead-copper carbonate and sulphide ore. During this period, under the stimulus of high metal prices, the main shaft was sunk to below the 300 level and the property equipped for air drilling.

The mine was idle from February 1920 until the fall of 1924, when it was taken over by the Hayward-Richard Leasing Co. This company deepened the shaft to the 400 level and explored the vein on that level. Some small ore bodies were stoped south of the shaft, and in the spring of 1928, after courageous drifting northward through a long barren zone, the present extensive ore shoot was discovered. In June 1928 a controlling interest was sold to the Asarco Mining Co., a subsidiary of the American Smelting & Refining Co.

[34] Lasky, S. G., Geology and ore deposits of the Groundhog mine, Central district, Grant County, N. Mex.: New Mexico Bur. Mines and Mineral Resources Circ. 2, 1930.

The total production of the mine to November 1, 1930, was approximately 123,260 tons of ore. Milling and smelting returns are not available, so the net value of this production is not known, but it is estimated at approximately $2,250,000. Production from January 1 to November 1, 1930, was 39,512 tons of ore which contained 25 to 30 percent of the valuable metals. This is indicative of the importance which the property has attained.

Lasky in the paper cited has discussed in detail the geologic features of the Groundhog mine. What follows is a summary of the important relations.

Granodiorite dikes have invaded the quartz diorite porphyry (Fort Bayard laccolith) along a fracture zone trending N. 35° E., about 200 feet wide. The quartz diorite porphyry here, as at many other places, contains slices and masses of in-faulted or "included" Colorado shale. This is not surprising if the nature of the laccolithic intrusion is taken into account. The slices and blocks may be regarded as fragments of displaced roof or floor engulfed in the advance of the magma, the progress of which at many places was cross-cutting, at least in detail. Lasky finds that there has been subsequent faulting along most of these shale and diorite contacts, the precise date of which it is difficult to establish but which in the main was certainly before the eruption of Tertiary lava. The invading granodiorite dikes have in turn been fractured along with their wall rocks, and it is within these fractures or fracture zones that the ore occurs. Lasky finds also that many of the dike contacts are now fault planes. He continues:

Pyrite occurs through the ore in more or less crystalline particles, some of which are well developed, and in fine-grained crystalline aggregates. Crystalline pyrite also occurs disseminated in some of the wall rock, particularly in the quartz diorite.

Sphalerite is in general the most abundant mineral, though, as noted above, leady streaks occur in which sphalerite is unimportant. The sphalerite is black or deep-brown marmatite. A preliminary microscopic examination shows that it contains chalcopyrite as rows of dots and threadlike veins which follow a pattern suggestive of grain boundaries. A narrow quartz-chalcopyrite vein was noted in one specimen of sphalerite. Chalcopyrite, in addition to the above-described microscopic particles, occurs also as megascopic masses in the ore.

The galena is both coarse-grained and fine-grained and in all specimens examined was the last sulphide deposited.

Gangue is scarce in the ore shoot. It consists mainly of quartz and sericite and occurs chiefly in stringers cutting the ore. Quartz combs are common in these stringers. In that part of the vein where sulphides are less prominent or are absent the vein consists of massive quartz, which at the outcrop is a reddish jaspery material.

In general the mineral sequence is as follows: Pyrite, sphalerite, chalcopyrite and quartz, galena, quartz and sericite.

The quartz diorite adjacent to the vein is sericitized, silicified, and pyritized, and generally altered beyond recognition. The granodiorite on the contrary, though older than the ore, is comparatively fresh and at least recognizable, even where in direct contact with massive sulphides. * * *

The difference in degree of alteration between quartz diorite and granodiorite is surprisingly great. Either these rocks are inherently susceptible to alteration to a different degree or else they both were not bathed by the same solutions. * * *

Presumably the sill was fractured prior to intrusion of the granodiorite, and the rock along this fractured zone was altered by its own concomitant or related magmatic juices. These juices may have carried no metals, for the pyrite may have resulted from the femic minerals of the rock.

Later intrusions of granodiorite in the form of dikes followed the earlier fracturing, and these in turn were fissured and faulted. The granodiorite juices were heavily metal-laden, though not so rich in those constituents which promote intense rock alteration. These solutions probably furnished the ore, which to a very great degree seems only to have filled the available openings. The few pyrite specks in the granodiorite probably resulted from alteration of the femic minerals and if so are different in origin from the pyrite of the ore.

The vein system described was deeply eroded and blanketed by Tertiary lava. Subsequent faulting and erosion have exposed the ore deposits at the surface. The principal post-lava fault practically parallels the vein system, dips about 45°, and is downthrown on the east about 200 feet. The vein system is cut off by this fault at the southwest end, on the Lucky Bill claim.

Lasky says:

Four classes of ore have been mined—(1) lead carbonate ore with a little copper and silver, (2) secondary copper ore, (3) argentiferous zinc-lead-copper sulphides, and (4) galena ore.

The main ore body occurs as a well-defined shoot within the vein. Early work south of the main shaft encountered some small and irregular bodies of ore, but as much as 500 tons of ore was seldom in sight at one time until the main shoot was discovered. This shoot as thus far developed is about 1,000 feet long and 40 feet wide at the thickest part. It has been developed to a depth of 400 feet below the surface, with splendid ore in sight at that depth. The top of the shoot is said to be near the third level in general, though a prong reached the surface and some high-grade oxidized lead ore was mined from it there. It is stated that the southwest end of the shoot is about 200 feet or so northeast of the main shaft. Where explored on the fourth level this interval is practically barren of sulphides. The northeast end of the shoot has not yet been encountered.

Where the shoot was first discovered a 3-inch stringer of sulphide was followed for 65 feet before it began to open into a minable ore body.

The primary ore consists of a massive argentiferous mixture of sphalerite, galena, pyrite, and chalcopyrite. Locally the ore has a suggestion of banding in zincky and leady streaks, some of which are sufficiently pure to be sent directly to the smelter. The relationship, if there is any, of chalcopyrite to this semibanding is not apparent.

The primary ore now being mined has the following average composition: Silver, 8 ounces per ton; lead, 8 percent; copper, 4 percent; and zinc, 16.5 percent. The ore to which this analysis refers shows a very incipient secondary copper enrichment, but this is so slight that it can have no more than an insignificant effect on grade.

The present writers suggest, in view of observations at Santa Rita and Hanover, that the fracturing and intense alteration of the quartz diorite porphyry followed the intrusion of the larger masses of granodiorite but somewhat preceded the later granodiorite dike intrusions.

The Ivanhoe mine, on the extension of this fracture zone about 3,000 feet to the northeast, has been worked for lead and copper ores. The ore bodies are of the same general type as those just described. The lode has resulted from a combination of fissure filling and replacement along a contact between a granodiorite dike and shaly limestone.

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