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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGY AND ORE DEPOSITS OF THE LITTLE HATCHET MOUNTAINS

HIDALGO AND GRANT COUNTIES NEW MEXICO

Prepared in cooperation with the
STATE BUREAU OF MINES AND MINERAL RESOURCES
OF THE NEW MEXICO SCHOOL OF MINES

GEOLOGICAL SURVEY PROFESSIONAL PAPER 208

UNITED STATES DEPARTMENT OF THE INTERIOR
J. A. Krug, Secretary
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Professional Paper 208

GEOLOGY AND ORE DEPOSITS OF THE LITTLE HATCHET MOUNTAINS

Hidalgo and Grant Counties New Mexico

BY
SAMUEL G. LASKY

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CONTENTS

ILLUSTRATIONS

ABSTRACT

The Little Hatchet Mountains cover about 75 square miles west of the town of Hachita in southwestern New Mexico. The north half of the range, in Grant County, contains the Eureka silver-lead mining district, and the south half, in Hidalgo County, contains the Sylvanite gold-mining district. The earliest metal-mining locations in the Little Hatchet Mountains were made in 1871, but in the 67 years to 1937 only about 60,000 tons of ore was mined, having an estimated gross value of $1,250,000 or less. Most of this production came from five ore shoots, the smallest of which, in the Sylvanite district, yielded 1,300 tons of ore, and the largest, in the Eureka district, about 25,000 tons. The geological survey of the range was made in cooperation with the State Bureau of Mines and Mineral Resources of the New Mexico School of Mines as part of a larger projected survey of the whole of Hidalgo County.

The Little Hatchet Mountains, one of the familiar northward-trending desert ranges of the southwestern United States, are completely encircled by valley fill. There is some probability that the range is a fault-block mountain. In plan the range is long and carrot-shaped—broad, low, and diffuse in the Eureka half, compact, narrow, and rugged in the Sylvanite half, the dividing line following the trace of the Copper Dick fault. At one time the range appears to have been surrounded by a gravel-covered pediment; this gravel in effect separated the north and south halves of the range, but current erosion is removing the gravel and restoring the continuity of bedrock exposures.

Water is obtained from four small springs or from wells in the surrounding valley fill. Depth to water ranges in the mountains from 10 to 225 feet and in the valleys from 15 to about 290 feet. The valley waters in general are suitable for any uses to which they might be put in a mining camp, but the mine waters are unsuited in the raw state for any but milling purposes.

With minor exceptions, all the sedimentary rocks appear to be of Trinity (Lower Cretaceous) age. The exceptions include only the Quaternary alluvium, a few beds in the Tertiary pyroclastics, and possibly one small isolated exposure of uncertain age. Pennsylvanian limestone is exposed in an isolated hill at the extreme south tip of the range and constitutes a geologic link with the Big Hatchet Mountains immediately south. Five disconformities have been recognized among the Lower Cretaceous beds, but disconformities that are strong in some places merge elsewhere into comfortable contacts. One of the disconformities cuts out a measurable thickness of as much as 1,500 feet of beds, one perhaps well over 2,000 feet, and one over 5,000 feet. The Lower Cretaceous rocks have been divided into seven formations to which local names have been applied, the group being roughly equivalent in age to part of the Bisbee group of southeastern Arizona. In general, they are composed of beach and near-shore marine deposits of shale, sandstone, limestone, and conglomerate, but they also include several thousand feet of interlayered volcanic rocks, as shown in the condensed section:

Section of Lower Cretaceous rocks (Bisbee group) in the Little Hatchet Mountains, New Mexico

Formation	Thickness (feet)	
	Eureka district	Sylvanite district
Tertiary volcanic rocks.		
Angular unconformity.		
Bisbee group:		
Skunk Ranch conglomerate: Predominantly coarse red conglomerate and red shale; includes a volcanic member locally	3,400	Absent

Section of Lower Cretaceous rocks (Bisbee group) in the Little Hatchet Mountains, New Mexico—Continued

Formation	Thickness (feet)	
	Eureka district	Sylvanite district
Erosional contact.		
Playas Peak formation: Fresh-water shale and sandstone overlain by massive marine limestone and locally underlain by coarse basal conglomerate	800–2,000	3,000 or more
Erosional contact (conformable contact in Sylvanite district).		
Corbett sandstone: Chiefly varicolored sandstone, in part quartzitic	1,500–3,000	4,000
Howells Ridge formation: Lower part red shale, mudstone, limestone, sandstone, and conglomerate; layer of volcanic rocks locally recognizable. Upper part massive limestone	1,100(?)–5,200(?)	4,900 ±
Erosional contact.		
Hidalgo volcanics: Andesite and basalt flows and subordinate pyroclastic rocks; a 200-foot sedimentary member intercalated at one horizon. Topmost part faulted from view	900–5,000+	Absent
Erosional contact.		
Ringbone shale: Fresh-water shale, and sandstone, locally including a basal conglomerate; upper part includes two volcanic members	0 — 650±	Absent
Erosional contact.		
Broken Jug limestone: Limestone and interbedded sandstone, shale, and limestone conglomerate, but showing considerable local variation. In Eureka district includes two horizons of massive limestone	5,000(?)	3,400 ±
Base of section concealed by Quaternary fill.		

The total thickness exposed in the Sylvanite district is about 15,300 feet. The total thickness in the Eureka district ranges from 12,700 feet, obtained by adding minimums in the above table, to 24,150 feet, obtained by adding maximums; the actual thickness present in a continuous section in the Eureka area, however, is from 17,000 to 21,000 feet, the thickest part of some formations overlying or underlying the thinnest part of others.

The shore line of the rapidly subsiding geosyncline in which the formations were deposited was near and at times within what is now the Eureka part of the range. Fossil *Orbitolina* are present in the massive limestone members of the Broken Jug, Howells Ridge, and Playas Peak formations; *Exogyra quitmanensis* and a large unnamed *Pecten* that Stanton says is characteristic of Taff's "Quitman bed" are present at two horizons in both the Broken Jug limestone and the Howells Ridge formation; and *Douvilleiceras* has been found at two horizons in the Broken Jug limestone. These are Trinity forms, and Stanton reported that he had "no hesitation" in assigning the age of the *Orbitolina*-bearing limestones as Glen Rose (late Trinity). Therefore the exposed thickness of beds of Glen Rose age alone is as much as 17,000 feet. No significant fossils have been found in the Skunk Ranch conglomerate, but because of its geologic history and lithologic

character this formation is assumed to belong to the underlying Trinity sequence.

Some of the formations resemble beds of Comanche age in nearby regions, but the repetition of zones of similar fauna and lithology, among other reasons, makes impossible any regional correlation of individual sedimentary formations. The Hidalgo volcanics are the equivalent of the early group of volcanic rocks in the Lordsburg mining district nearby, and they may be equivalent also to some andesitic rocks in Arizona and in Sonora and Chihuahua, Mexico.

The igneous rocks include 22 varieties grouped under 18 text headings and map units. In order of age they include (1) the Lower Cretaceous volcanic rocks summarized above and a small mass of orthoclase gabbro that may be related; (2) diorite sills, later stocks of monzonite, quartz monzonite, and granite, and dikes of porphyry, lamprophyre, and aplite, of supposed late Cretaceous or early Tertiary age; (3) dikes and sills of latite and felsite supposedly of Miocene age, later Miocene(?) pyroclastic and flow rocks, latite dikes apparently equivalent to some of the flows, and pods of granite along the Copper Dick fault; and (4) small masses of Pleistocene basalt. The mineralogic variations in the several rocks to the close of the late Cretaceous or early Tertiary stage suggest an orderly differentiation sequence. (See pl. 4.)

Three stocks crop out—a small mass of monzonite near Old Hachita in the Eureka district, a composite mass of monzonite and later quartz monzonite at Sylvanite, 6 miles south, and a composite mass at the extreme south tip of the range composed of three varieties of granite of different ages. The outcrop near Old Hachita, however, is interpreted as the faulted-off top part of the monzonite-quartz monzonite stock at Sylvanite. Before faulting, this Sylvanite-Old Hachita stock lay sill-like, with generally concordant floor and roof, at and near the top of the Broken Jug limestone for 7 miles or more and tapered from a thickness of about 7,000 feet and a width of 4 miles in what is now the Sylvanite district to a thickness of about 2,500 feet and a width of 2 miles in what is now the Eureka district. The composite granite stock, which lies near the top of the sedimentary section, seems to be similarly sill-like and wedge-shaped, though more stubby; its thickness normal to the bedding is 1,100 feet. The two stocks probably join somewhere below the surface as parts of a larger discordant composite body that came up through the Paleozoic and older rocks and broke into sill-like streamers upon reaching the generally thin-bedded Lower Cretaceous formations. The Sylvanite-Old Hachita stock was injected under a cover of at least 10,000 feet and made way for itself by the combined methods of stoping, assimilation, igneous replacement, and the laccolithic and sill mechanisms; roughly three-fifths of the space occupied by the present outcrop at Sylvanite was acquired by obliterating the sediments, and two-fifths by pushing them apart. Conclusions regarding emplacement of the composite granite stock are less detailed, but granitization was a factor.

Three broad folds trend northwestward to westward across the range, all broken by later faults. These are the Vista anticline at the north end of the range; its companion, the Howells Wells syncline, near the middle; and a monoclinal block to the south, which is believed to have been the south limb of a second anticline before faulting. These and the subordinate folds upon their flanks are related to four stages of folding—(1) some preintrusion tilting presumed to have been the earliest expression of the Laramide orogeny; (2) the main stage of folding, in the interval between injection of the diorite sills and injection of the monzonite stocks; (3) drag folding against the Copper Dick fault; and (4) folding of the Miocene(?) rocks, in part along earlier fold axes.

The major faults are (1) the Hatchet Gap fault, which has a stratigraphic throw of about 25,000 feet or more and either is itself a thrust fault that brings the Paleozoic rocks of the Big Hatchet Mountains against the younger rocks of the Little Hatchets or is related to such a fault; (2) the S-shaped Copper Dick fault, traceable full across the range and having a net slip estimated at about 15,000 feet; (3) the Miss Pickle fault, a strike fault also traceable full across the range and having a probable maximum net slip of about 7,000 feet at 15° from the horizontal; (4) the National fault, a transverse fault having a net slip measurable probably in the low thousands in a direction roughly parallel to the dip of the beds; and (5) the Howells Wells fault, whose net slip is indeterminable but whose throw ranges from 450 feet or more on one side of the fault, through zero at a hinge point, to about 1,000 feet on the other side. Five stages or episodes of movement can be recognized, extending from preintrusion times, when some bedding-plane faults related to the first stage of folding were formed, to post-Miocene time.

The Copper Dick fault has duplicated the full sedimentary section and the Sylvanite-Old Hatchet stock within it, and thus has counterfeited two separate centers of intrusion and mineralization. This situation is the key to the geology of the Little Hatchet Mountains and to appraisal of the ore-bearing possibilities of the range.

Each of the stocks is bordered by a "contact-metamorphic" halo, which is noteworthy for its zoning, for its extent, and for the time relation between metamorphism and emplacement and solidification of the igneous rocks. Much new material, largely soda, was added to the contact zone. Sodic juices began to collect in the Sylvanite-Old Hachita stock at a late pyrogenetic or incipient deuteric stage and to escape into the surrounding rocks at about that time; and there apparently was an essentially continuous expulsion of metamorphosing solutions from then until after emplacement of the satellitic porphyry dikes. The ore deposits evidently were formed by further accessions of the metamorphosing solutions directed into the vein fissures as these were opened. Sodium was a characteristic element throughout this sequence.

The sequences of igneous intrusion and mineral deposition in the Little Hatchet Mountains are similar to those in the Lordsburg and Santa Rita mining districts nearby; indeed the igneous history of the Little Hatchet Mountains is a blend of the igneous histories of the other two areas. Three periods of mineralization can be recognized in the Little Hatchet Mountains—the period of ore formation, which is immediately related to the stocks, and two later periods, both trivial commercially, related to the Miocene(?) rocks. In addition, oxidation and erosion have given rise to turquoise deposits in the Eureka district and to gold placer deposits in the Sylvanite district.

In both the Eureka and Sylvanite districts the ore deposits lie within or near the stocks. The deposits are few, and the veins are comparatively short and for the most part tight. They generally lie along lamprophyre dikes in the Sylvanite district and along monzonite porphyry dikes in the Eureka district. The typical ores of the Sylvanite district contain native gold, tellurides, and minor sulfides, principally arsenopyrite and chalcopyrite, in a gangue of vein silicates, quartz, and calcite. The ores of the Eureka district contain base-metal sulfides in a gangue that is chiefly manganosiderite. Mineralogically, there are almost as many types of deposits in each district as there are major prospects, but the diversity seems due to the fact that at particular stages of deposition some veins or parts of veins received a greater supply of mineral matter than others. Fifty-eight minerals, including both hypogene and supergene, have been identified.

Each district shows three analogous stages of deposition, and what can be determined of the mineral successions indicates a close matching of many details. Wall-rock alteration everywhere is meager. The Eureka and Sylvanite districts were originally continuous, laterally one above the other in a zone around the Sylvanite-Old Hachita stock, prior to the major movement along the Copper Dick fault; and the mineralogic details of the deposits, studied in the light of this structural background, suggest a zonal distribution, with a simple interfingering of the Eureka mesothermal deposits above into the Sylvanite hypothermal deposits below.

The mineral possibilities of the range are appraised in a special section of the report, and the conclusion is reached that the supposed barren part between the Eureka and Sylvanite districts contains a deep mineralized zone. Deductions are drawn concerning the depth to the most promising parts of this zone, the character of the ore in it, the size of the shoots, and the structure and persistence of the veins. The possibilities of future prospecting in the Sylvanite and Eureka districts themselves are discussed briefly, and a few practical comments are made concerning some of the mines.

Twenty-seven mines and prospects are described in detail in the last section of the report.

Geology and ore deposits of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico

By Samuel G. Lasky

INTRODUCTION

PURPOSE AND SCOPE OF THE REPORT

This report on the Little Hatchet Mountains of New Mexico has been written with two purposes in mind—to aid in understanding the ore deposits of the range and their geologic setting and to present a starting point for understanding the geology and ore deposits of the general region.

The Little Hatchet Mountains are in the little-developed southwest corner of New Mexico and constitute one of the isolated desert ranges characteristic of that part of the State. Most of these ranges consist of barren volcanic piles of comparatively recent (middle Tertiary) age, but at a number of places fairly large areas of the older rock are exposed. In such areas signs of ore deposition invariably have been found, and at some places mines have been developed, but in only one, the Lordsburg district,[1] have the mines been of commercial importance. From 1904 to 1933 the Lordsburg district produced ore valued at nearly $19,500,000, whereas the aggregate production from all the other areas, which include seven mining districts, has amounted, since their discovery in the 1870's, to only about $2,000,000.

Available geologic knowledge prior to the present report suggested that the ore deposits were related to igneous activity and associated metamorphism of probable late Cretaceous or early Tertiary age. The low productivity of the region therefore presented a problem of considerable interest, for the region lies within a metalliferous province, most of whose highly productive deposits seem to be of that geologic age and affiliation. Moreover, it is only through the accident of erosion that the known deposits have been exposed, and it is conceivable that unsuspected deposits, hints to whose possible existence may be obtained by study of the mineralized areas adjacent to the Tertiary volcanic cover, may lie buried beneath the Tertiary rocks. In addition, it had long been suspected,[2] and the suspicion was recently confirmed in the Lordsburg mining district,[3] that part of the supposed Tertiary volcanic rocks of southwestern New Mexico are really older and consequently may be host to the ore deposits of late Cretaceous or early Tertiary age rather than a cover over them.

[1] Lasky, S. G., Geology and ore deposits of the Lordsburg mining district, Hidalgo County, N. Mex.: U. S. Geol. Survey Bull. 885, 1938.

[2] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 296, 1910. Darton, N. H., "Red beds" and associated formations in New Mexico, with an outline of the geology of the State: U. S. Geol. Survey Bull. 794, p. 62, 1928.

[3] Lasky, S. G., op. cit.

Much of this general area lies in Hidalgo County, and accordingly the cooperative agreement between the Federal Geological Survey and the State Bureau of Mines and Mineral Resources of the New Mexico School of Mines was extended in 1934 to permit a survey of the whole of that county, in accordance with the policy of the State bureau of issuing county reports. The Little Hatchet Mountains were chosen as a starting place for this enlarged project, even though the range extends into another county, because they contain the largest of the mineralized areas and have been more productive than the others and because of the many requests for information received by the Geological Survey and the New Mexico Bureau of Mines. A preliminary visit was made to the range in August, 1934, and detailed mapping was started on September 19 of that year and continued until December 14. The topographic base used consisted of published quadrangle maps of the Geological Survey on a scale of 1:62,500. Most of the period from June 6 to August 6, 1935, was spent in remapping critical and complicated parts on a larger scale and in studying the accessible mines. During the second visit I was assisted by R. F. Pettit. Headquarters thereafter were established with the New Mexico Bureau of Mines at Socorro, and short visits were made to the Little Hatchet Mountains whenever the need for additional information arose.

The area mapped covers about 85 square miles and includes, in addition to the Little Hatchet Mountains proper, all the hills in the gap between the Little and Big Hatchet Mountains and all that part of the Coyote Hills included in the topographic base maps.

PREVIOUS WORK IN THE LITTLE HATCHET MOUNTAINS

The Little Hatchet Mountains were first visited by an organized geologic survey in 1905, when Waldemar Lindgren examined the mines of the Eureka district at the north end of the range in the course of a reconnaissance survey of the ore deposits of New Mexico.[4] Later, in 1909, J. M. Hill visited the Sylvanite district in the south part of the range to obtain further information for Lindgren's report. Lindgren and Hill classified a large part of the sedimentary rocks of the range as of Paleozoic age but thought some of them might be Cretaceous. They observed the intrusive rocks and the associated con-

[4] See bibliography below for this and other references in this section.

tact metamorphism, and Hill thought the mass at Sylvanite was laccolithic; the granite at Granite Pass he erroneously described as being faulted against the sedimentary rocks north of the pass by a "fault of considerable vertical displacement." Neither Lindgren nor Hill did any geologic mapping.

In 1911 D. B. Sterrett of the Geological Survey published an excellent description of the turquoise mines of the Eureka district, and in 1913 the ground-water resources of the adjacent Playas and Hachita Valleys were studied by A. T. Schwennesen, also of the Geological Survey. About 1920 N. H. Darton prepared a reconnaissance geologic map of the Little Hatchet Mountains to help complete his geologic map of the State, which was published in 1928. Darton confirmed Lindgren's and Hill's belief that some of the rocks might be Cretaceous by finding Comanche (Lower Cretaceous) fossils, but he ascribed most of the sedimentary rocks to the Magdalena group of Pennsylvanian age. He believed that the Comanche rocks included formations of both Trinity and Washita ages, indicating them on his map as "Sarten sandstone and underlying limestone" and stating [5] that the limestones "resemble the Mural limestone of the Bisbee and Douglas region, Ariz., to which doubtless they are equivalent." He suspected the truth about the late age of the granite at Granite Pass, but failed to recognize that it is part of a granite mass occupying the entire southern tip of the range, for he mapped the dark granite south of the pass as sedimentary rock of Comanche age.

These reports, particularly those of Lindgren, Hill, and Darton, have furnished the principal information heretofore available concerning the Little Hatchet Mountains. Other publications that include information on the geology or mining industry of the range are given in the bibliography below, which is believed to be essentially complete. Some information has been published through more than one medium or has been repeated in papers by later authors, but all publications are cited for the convenience of those who may not have access to the original or more complete reports.

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[5] Darton, N. H., op. cit., p. 38.

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PRINCIPAL RESULTS OF THE PRESENT SURVEY

The chief result of the present survey, so far as the Little Hatchet Mountains alone are concerned, is the conclusion that the north or Eureka half of the range, with its intrusive rocks and ore deposits, is the faulted-off upward continuation of the south or Sylvanite half of the range. The displacement occurred along a remarkable S-shaped fault whose net slip amounts to about 15,000 feet; this fault, which I have named the Copper Dick, is the key to most of the problems concerning the geology and ore deposits of the Little Hatchet Mountains.

A fault in Hatchet Gap that brings the Pennsylvanian rocks of the Big Hatchet Mountains against the Cretaceous or younger rocks of the Little Hatchet Mountains may be of regional significance.

Another result, of both local and regional significance, is the recognition that essentially all the exposed sedimentary rocks, which have an average aggregate thickness close to 19,000 feet, are of Trinity (Lower Comanche) and, perhaps, of late Trinity (Glen Rose) age. The Little Hatchet Mountains, therefore, expose a Comanche or Lower Cretaceous section, which, even though apparently confined to part of the Trinity interval, is much thicker than any Comanche section previously described. An important corollary, from the viewpoint of the miner, is that the ore deposits lie at a geologic horizon thousands of feet higher than supposed and thousands of feet higher than the Paleozoic rocks that have been the most productive formations in the principal mining districts of the province. Included in the Trinity section are as much as 5,700 feet or more of basaltic flows and breccias whose main part appears to be a continuation of the early group of volcanic rocks, locally called "andesite," in the Lordsburg mining district.

Several features of the igneous rocks and mineral deposits in the Little Hatchet Mountains resemble those of other mining districts in southwestern New Mexico; for example, the igneous sequence is similar to that of the Lordsburg district and almost identical with that of the Santa Rita district, the Eureka district in the north half of the range being a blend, as it were, between the two. Several types of ore deposits have been recognized in the range, and mineralogic details suggest a similarity with the tourmaline-copper deposits of the Lordsburg district and with the bismuth-bearing deposits of the Apache Hills, on the east side of Hachita Valley. A quartz-lamellar calcite vein in the Tertiary volcanic rocks presumably belongs to the same period of mineralization as the silver-bearing lead deposit in the Red Hill district in the Animas Mountains on the west side of Playas Valley, the silver-gold veins of the Mogollon district, and the manganese deposits in the Little Florida Mountains near Deming.

Other results include quantitative estimates of the effectiveness of the several possible modes of intrusion in the emplacement of the stocks, a quantitative statement of the minimum depth of intrusion of the main stock, the conclusion that the pre-Miocene(?) igneous rocks may form an orderly differentiation sequence, and the conclusion that there seems to be a closer genetic relation between the ore deposits and the igneous rocks now exposed than is ordinarily observable.

There is reason to believe that the cause of the low productivity of the range has been determined. New prospecting ground has been discovered by the survey, and the distribution of this new ground, the probable depth to the mineralized zone, the structure and persistence of the veins that may be present, the probable size of the ore shoots in them, and the character of the ore are discussed in the body of the report.

ACKNOWLEDGMENTS

I wish to take this opportunity to thank the many persons whose kindness and cooperation have aided me in my field work and in the preparation of the report. Mr. F. W. Snyder of the American Group of Mines Co. gave freely of his time and energy during my stay in the field, and Mrs. Maude J. Fowles, owner of the American and National groups of claims, graciously permitted me to establish field headquarters at the camp and placed at my disposal all records pertaining to her properties. Mr. and Mrs. A. E. Bader, Albert Fitch, Mike Wilcox, Arthur Morgan, and George Blood cooperated in my examination of the properties with which they were individually connected. Postmaster Fred Brown of Hachita extended many courtesies beyond his official capacity.

E. H. Wells, Director of the New Mexico Bureau of Mines and Mineral Resources at Socorro, placed all facilities of the bureau at my disposal during preparation of this report, and C. E. Needham, S. B. Talmage, and A. Andreas, geologists of the bureau, were of assistance in discussing some of the problems involved. Some problems also have been discussed with my associates on the Geological Survey, and I am particularly indebted to James Gilluly and T. B. Nolan for a critical reading of the entire manuscript. Field conferences with James Gilluly, J. B. Reeside, Jr., and H. G. Ferguson gave a more substantial basis to my interpretations of the geology of the area. Members of the Metallurgical Division of the Federal Bureau of Mines advised on one aspect of the report.

GEOGRAPHY

LOCATION AND ACCESSIBILITY

The Little Hatchet Mountains are in the southwest corner of New Mexico and about 15 miles west of the jog in the international boundary. The range is southwest of the town of Hachita and extends from an east-west line 3½ miles north of the town due south for 16 miles; it occupies parts of the Hachita, Big Hatchet Peak, and Playas quadrangles and lies partly within Hidalgo and partly within Grant County, the county line extending due west through the range near Howells Wells. (See fig. 1.) The north half of the range, in Grant County, contains the Eureka silver-lead-zinc mining district, and the south half, in Hidalgo County, contains the Sylvanite gold mining district.

The town of Hachita, which has a population of 202 (1930 census), is on the south line of the Southern Pacific Railroad. A branch line for a long time connected Hachita with Lordsburg, 38 miles north-

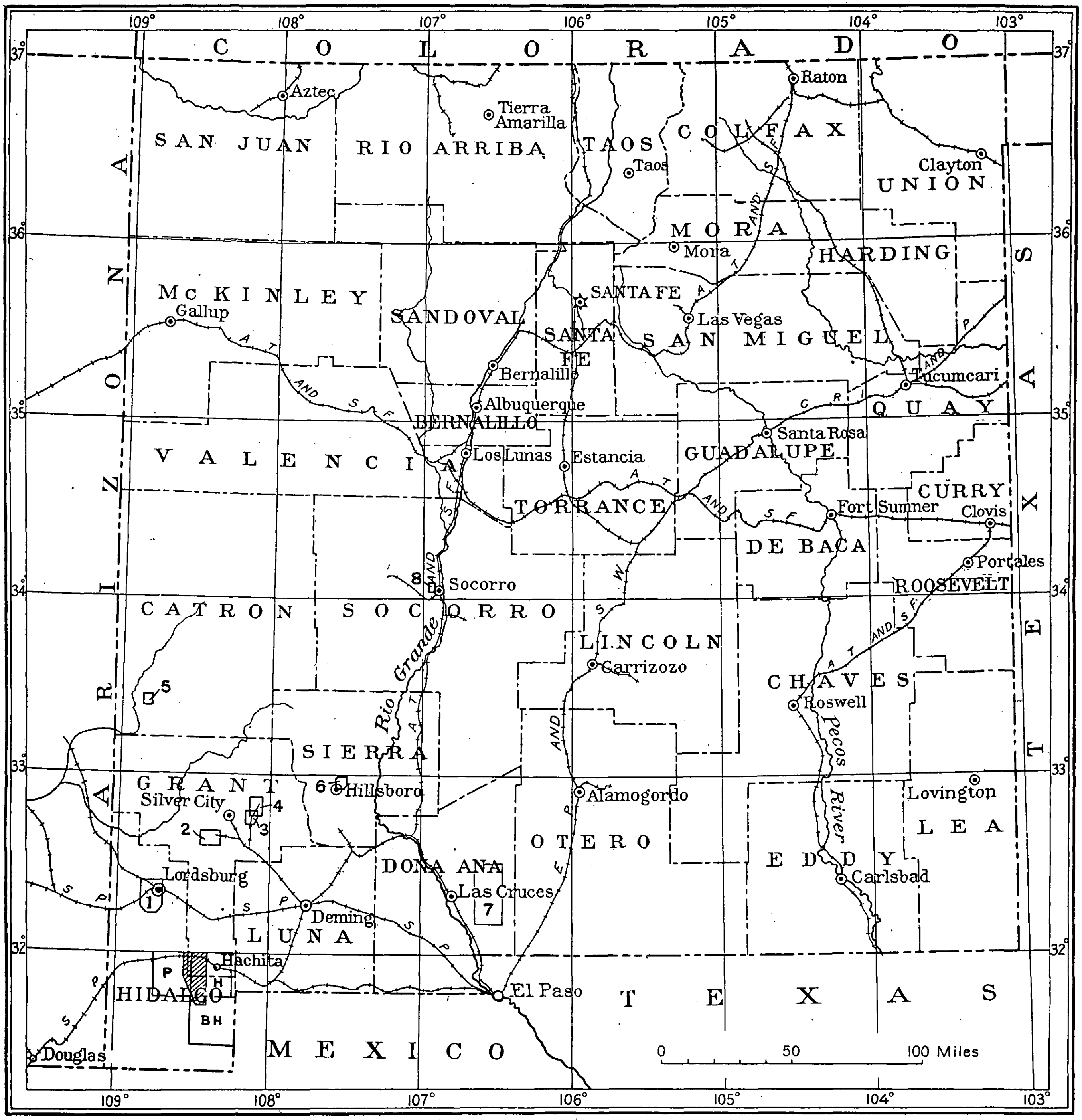


FIGURE 1.—Index map of New Mexico showing location of the Little Hatchet Mountains and their position with respect to the Hachita (H), Big Hatchet Peak (BH), and Playas (P) quadrangles. Shown also are the locations of other metalliferous areas in New Mexico for which Federal or State reports have been issued containing detailed geologic maps, on a scale of 1:62,500, or greater. (1) Lordsburg district, U. S. Geol. Survey Bulletin 885; (2) Tyronne district, U. S. Geol. Survey Professional Paper 122; (3) Bayard area, U. S. Geol. Survey Bulletin 870; (4) Santa Rita area, U. S. Geol. Survey Bulletin 859; (5) Mogollon district, U. S. Geol. Survey Bulletin 787; (6) Hillsboro district, New Mexico Bur. Mines Bulletin 10; (7) Organ Mountains, New Mexico Bur. Mines Bulletin 11; (8) Socorro Peak district, New Mexico Bur. Mines Bulletin 8.

west on the north line of the Southern Pacific, but it was dismantled in December 1934. A 19-mile dirt highway extends due north from Hachita to a junction with the oiled southern United States Highway 80 at a point about midway between Lordsburg and Deming. Lordsburg and Deming are the commercial centers of the area, and Lordsburg is the county seat of Hidalgo County. State Highway 3, which is largely a third-class unimproved road, passes through Hachita, following the railroad westward from Columbus to a junction with United States Highway 80 near Rodeo, a mile from the Arizona-New Mexico Line.

Several roads branch from the Columbus-Rodeo highway and penetrate into different parts of the Eureka district. Another road leaves the highway 2 miles west of Hachita and enters the range at Howells Wells, extending thence westward through a low pass in the range and down the west side into Sylvanite. Ore from the main part of the Sylvanite district is carried over this road, the distance to Hachita ranging from 13 to 18 miles. Other parts of the Sylvanite district are reached by a still more roundabout road that branches from the Hachita-Alamo Hueco road at Twelvemile wells, thence passing through Granite Pass and turning back into the range to end at the Gold Hill mine, a distance from Hachita of 21 miles. Most of the prospects are on one or another of these roads or on branches to them, but other prospects can be reached only by trail.

Ores from the Little Hatchet Mountains ordinarily are sent to the copper smelter of the Phelps Dodge Corporation at Douglas, Ariz., 100 miles southwest, or to the smelters of the American Smelting and Refining Company at El Paso, Tex., 117 miles to the east. Freight rates to Douglas ranged in 1935 from 80 cents a ton on ore having a value of $7.50 or less a ton to $5.10 a ton on ore having a value between $150 and $300 a ton. Rates to Douglas and El Paso are identical for ore having a value of $10 or less a ton, but for ore of higher grade the rates to El Paso are consistently 20 cents a ton higher. A custom mill owned by the Peru Mining Co. is situated at Wemple, New Mex., near Deming.

Power for mining operations must be generated locally. Lordsburg is the nearest point at which an electrical transmission line could be tapped.

CLIMATE AND VEGETATION

The Little Hatchet Mountains are in the semidesert region of southern Arizona and New Mexico and have the climate and vegetation characteristic of that region. Numerous varieties of the common desert plants and grasses are abundant in the valley areas surrounding the range and are scattered over its generally bare and rocky slopes. Scrub oak, cedar, and juniper grow locally in the mountains, here and there thickly, but there is no large timber, and even firewood must be hauled in. The entire country is grazing land, which has supported large herds of cattle and, in its northern part, small herds of goats.

The weather is clear and dry and is mild enough for outdoor work to be carried on throughout the year without material difficulty or discomfort. A Weather Bureau station has been maintained at Hachita since 1909, and according to its records[6] the average annual precipitation has been 10.96 inches, the range being from 4 to 18 inches. Only 30 to 40 days a year have more than 0.01 inch of precipitation, and nearly half the annual total falls during the months of July and August in afternoon thunderstorms of short duration, a single one of which may account for as much as 12 percent of the yearly total. The rainy season begins abruptly; April and May are by far the driest months of the year and June is almost as dry. The average annual temperature at Hachita is about 60°F. Temperatures above 100°F. are common during the summer months and may occur at any time from May to September, but the nights are generally cool, and the dryness of the air helps to make even the hottest days bearable. The average summer temperature is between 75° and 80°F. The average winter temperature is around 40°F., but the thermometer may fall to zero, or a little below, for short periods. The snowfall at Hachita averages 5.3 inches a year.

Storms throughout the region are generally local, a surprising feature to most newcomers. The hilly and mountainous areas have more rain and snow and milder summers than the valley areas, and in the Little Hatchet Mountains the annual precipitation is probably 3 or 4 inches greater than at Hachita and the temperature several degrees cooler, particularly during the summer months when even a small difference considerably affects the comfort and efficiency of outdoor workers.

SURFACE FEATURES

The southwest corner of New Mexico lies well within the Mexican Highland section of the Basin and Range Province, a physiographic subdivision characterized by isolated, northward-trending mountain chains separated by nearly flat basins or valleys that have been filled by detritus from the hills.[7] (See pl. 6, *A*.) The Little Hatchet Mountains are in the northern part of one such chain, which stretches northward from the Mexican border for 60 miles and includes, from the border north, the Alamo Hueco (Dog), Big Hatchet, and Little Hatchet Mountains, and the Coyote and Quartzite Hills. The Hachita Valley (Spanish, hatchet), which drains southward into Mexico, borders this chain on the east, and the Playas Valley, a closed basin whose axial part directly west of the Little Hatchet Mountains is generally occupied by a shallow lake, borders it on the west. The average altitude of the axial part of Hachita Valley is about 4,400 feet above sea level and that of Playas Valley a little less than 4,300 feet.

If detailed irregularities of the contact between bedrock and alluvium are disregarded, the foot of the Little Hatchet Mountains on both east and west sides follows smooth lines that cut without marked deviation across hard and soft rocks alike and across all structural features, the eastern foot being quite straight, the western foot gently curved and concave to the east. In plan the range is long and carrot-shaped—broad, low, and diffuse in the north half;

[6] Climatic summary of the United States, sec. 29, southern New Mexico: U. S. Weather Bur., 1930. Also later records to October, 1935.

[7] Fenneman, N. M., Physiography of western United States, pp. 379–393, 1931.

compact, narrow, and rugged in the south half. The natural dividing line between the halves follows the trace of the Copper Dick fault, which trends westward through the range a short distance south of the Grant-Hidalgo County line. The part north of the fault is cut down to a surface of late maturity. Tongues of debris reach far into that half of the range and cut the fringe into long spurs, and outlying hills detached from the main mass are common. In the higher parts of this half the topography tends to conform to the structure, and this half in the main is characterized by northwestward-trending ridges of the harder rocks. The most prominent feature, and one visible from a considerable distance in the valley, is Howells Ridge, a limestone ridge that extends from Howells Wells for 6 miles, its top, though breached at several places, having a generally uniform altitude between 5,500 and 5,600 feet above sea level. (See pl. 6, *A*.) South of this ridge, at the west edge of the range, is a jumble of naked peaks and cliffs of Tertiary volcanic rocks (see pl. 7, *A*), which constitute the sharpest topographic feature of the north part as seen from the west. The highest point of the north part, known as Playas Peak, rises among these cliffs to an altitude of 5,863 feet above sea level.

Northeast of Howells Ridge is a broad band of rounded hills and ridges, generally low and essentially all made up of old volcanic rocks. (See pl. 6, *B*.) On the east, in the vicinity of Old Hachita, this band is separated from Hachita Valley by a small frontal chain of limestone hills and buttes, but to the north and west it merges into low debris-covered ridges that in turn fade into the debris-filled valleys. The debris covering is very shallow in parts of this area, and at one place in what appears to be the valley proper bedrock is exposed only 2 or 3 feet below the gravel. Drainage lines in this low area largely disregard geologic structures. To the north are the northwestward-trending volcanic ridges of the Coyote Hills.

The area south of the Copper Dick fault is nearly triangular, tapering to a relatively sharp point at the last hill in Hatchet Gap 10 miles to the south. Its compactness, ruggedness, and continuity of crestline are in remarkable contrast to the generally low and open nature of the north half of the range. Low spurs of rock extend into Playas Valley at the extreme northwest tip of the triangle as parts of a dissected pediment whose rock-cut surface crops out in shallow draws a considerable distance from the main exposure and beneath as little as 2 feet of valley fill. At Granite Pass a broad rock-cut surface merges smoothly into the floors of Hachita and Playas Valleys (see pl. 6, *C*), but in general the south part of the range rises sharply above the valley fill on deeply ravined slopes that rise as much as 2,000 feet in a mile. Hachita Peak, just south of the Copper Dick fault, is the highest point in the range, having an altitude of 6,585 feet. It rises about 2,200 feet above the valley floors and more than 1,000 feet above the general altitude of the north half of the range. The crestline extends southward from the peak in a sinuous line that lies a little nearer the east edge of the range than the west. From Hachita Peak the crestline drops quickly to Broken Jug Pass, paralleling geologic contacts, but from there south it cuts directly across them at a fairly even altitude of about 5,800 feet, though breached along the soft granite of Granite Pass to within 200 feet of the level of the valleys. (See pl. 6, *C*.)

The two pediments mentioned above and the debris-covered ridges of the north half of the range are parts of an old and more extensive pediment that may have completely surrounded the Little Hatchet Mountains and that, in effect, isolated the north and south halves. The shallow passes followed by the roads from Howells Wells to Playas Valley are along arms of this old pediment, whose "knick line"—the line along which the surface of the pediment meets the steeper slope of the hills—tends to follow the 4,900-foot contour. The rock-cut surface of the pediment was at least in part covered by a veneer of gravel, patches of which still remain and are now in the process of being washed away. The most conspicuous of these patches are shown on the geologic map (pl. 1) as "high alluvium," together with other patches of "high alluvium" that indicate the debris-filled arroyos of the associated drainage, which seems to have followed much the same lines as the present drainage but at a level 20 or 30 feet higher. A bench in the surrounding valley fill, likewise being trenched by the present drainage, borders a good part of the range and forms a continuation of the pediment surface. This bench is well shown in Hachita Valley opposite Howells Wells, where it is about 20 feet high.

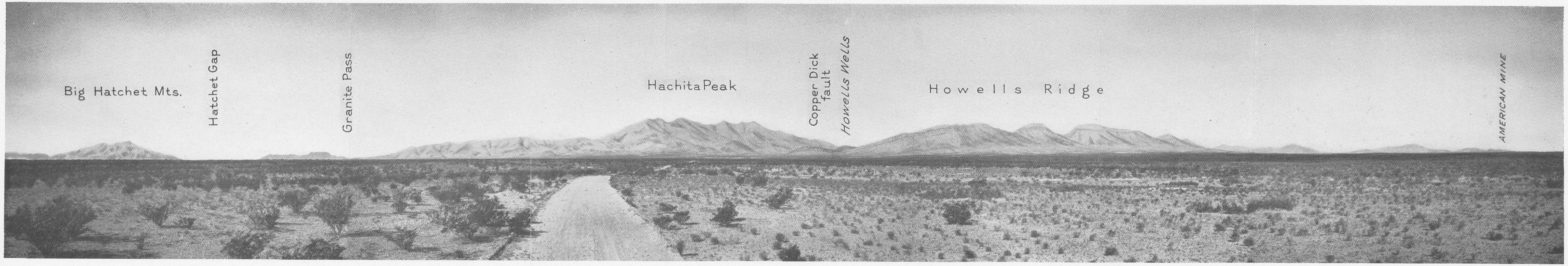
A larger part of the pediment than at present, perhaps most of it, was originally covered by the high alluvium, and figure 2 is a map of the range showing the approximate outline of bedrock exposures before the old gravel began to be removed by the present drainage, the edge of bedrock being arbitrarily sketched, in general, at the knick line of the pediment. Doubtless, more or less of bedrock was exposed than this drawing indicates, but the general situation must have been somewhat as shown, and the Little Hatchet Mountains at that time evidently consisted of a small desert range bordered on the north by a group of isolated hills.

The clay filling of the arroyos that cut the high alluvium, and of other tongues of valley fill that penetrate deeply into the hills, is at places trenched by rills and channels that have been carved in recent years and that are visibly modified and enlarged after every heavy rain. Some of these are major arroyos of the area and follow the lines of old roads whose ruts furnished incipient lines of drainage.

WATER SUPPLY

All water used in the Little Hatchet Mountains and vicinity is obtained from four small springs or from wells in the adjacent valleys. Much of it is brought from Hachita, where the railroad has put down two deep wells.

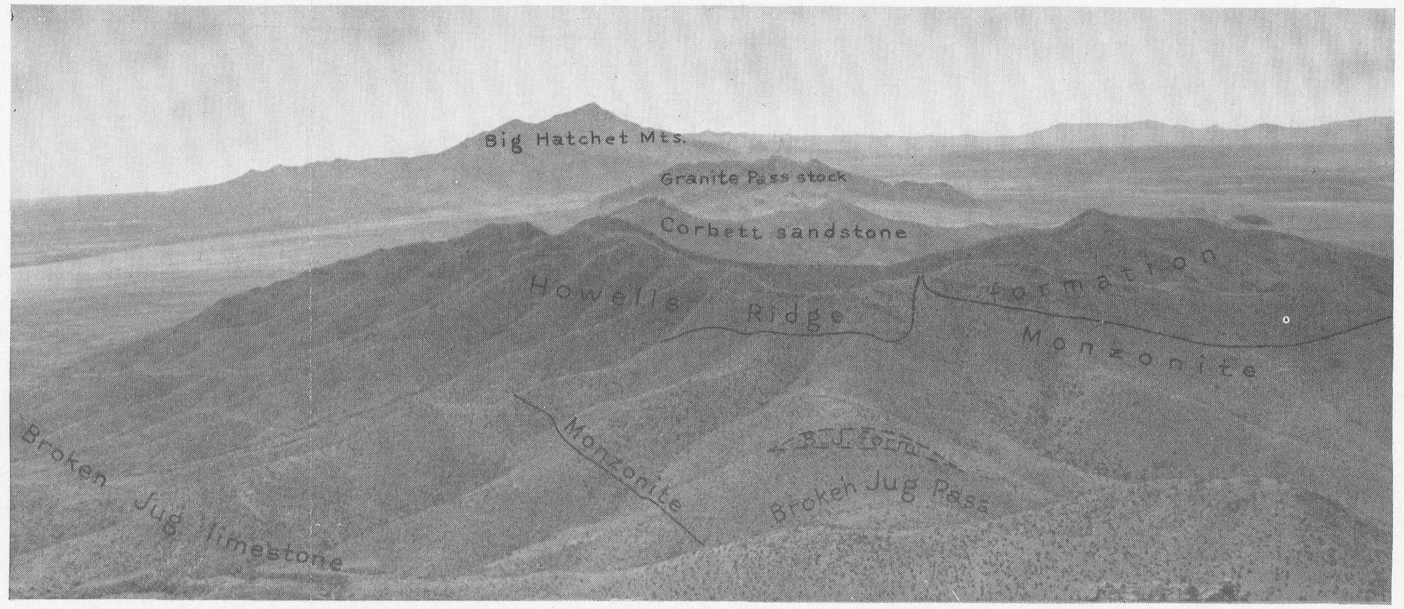
The springs include Howells Wells at the east edge of the range and just south of the Grant-Hidalgo county line, Cottonwood Spring at the west edge of the range and northwest of Sylvanite, Livermore Spring 1½ miles north of Cottonwood Spring, and a small unnamed trickle in the arroyo above the Green



A. PANORAMIC VIEW OF EAST SIDE OF LITTLE HATCHET MOUNTAINS.

B. ROUNDED TOPOGRAPHY OF THE HIDALGO VOLCANICS.

View westward. *American mine at extreme right.*



C. VIEW SOUTHWARD FROM HACHITA PEAK.

Shows topography of south part of range and general parallelism between intrusive contacts and sedimentary bedding. The light-colored rock just beyond the ridge of Corbett sandstone is the soft granite into which Granite Pass is cut, and the rough hills beyond are in the resistant porphyritic granite.

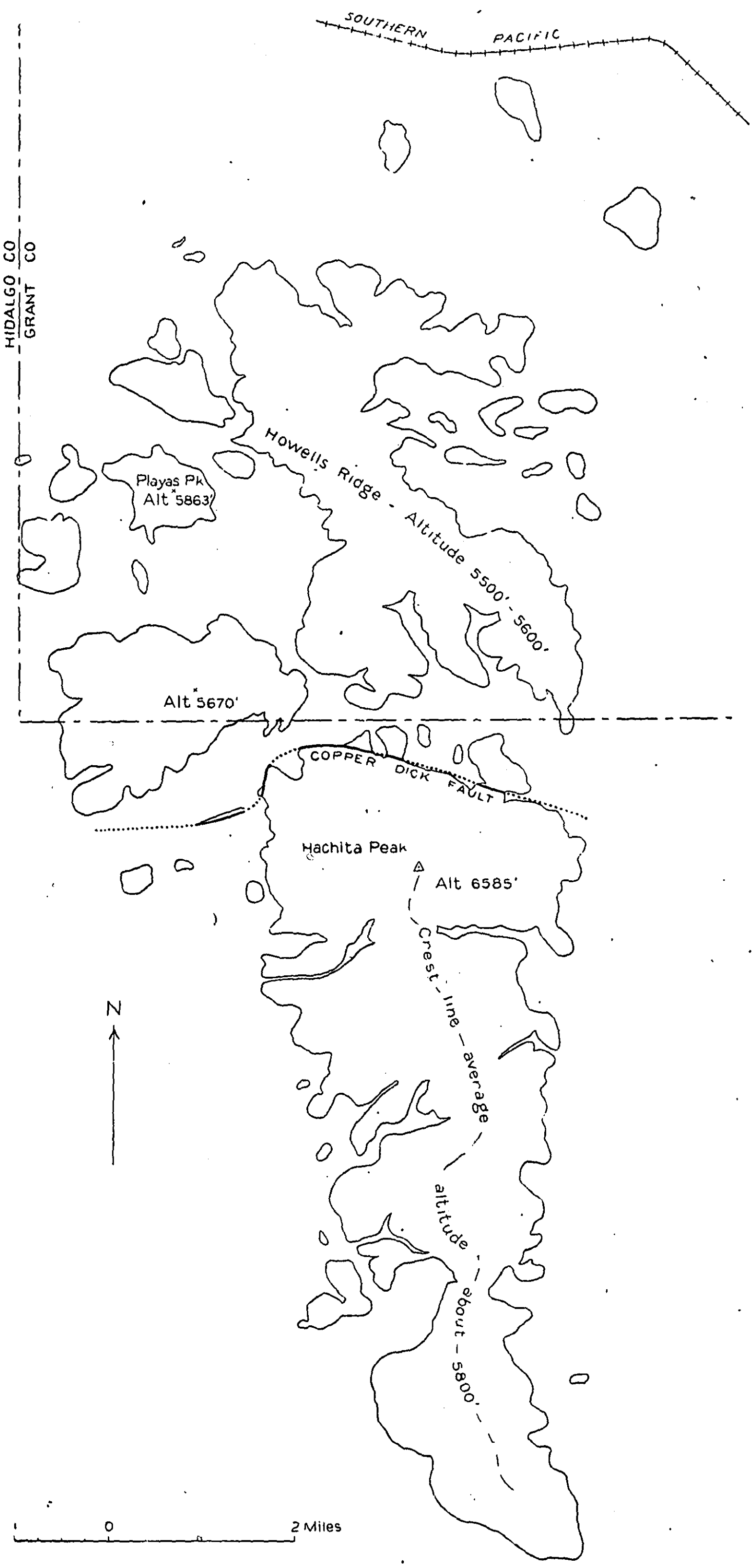


FIGURE 2.—Map showing probable outline of rock exposures in the Little Hatchet Mountains just before the beginning of the present stage of erosion, which is removing the gravel apron from the old pediment.

mine near Sylvanite. The water from Livermore Spring and Howells Wells is palatable and pleasant to the taste, but that from Cottonwood Springs is very hard. All arroyos in the range are normally quite dry except within a few feet of the springs. They may become temporary torrents immediately following one of the summer rains, as the rapidity of runoff from the steep slopes and the comparatively large area drained by each arroyo causes them to fill sometimes to the brim, and become impassable within a few minutes after such a rain begins, but they dry up within a few hours.

Though the water supply within the range itself is insignificant, water enough for any purpose connected with mining probably could be developed in Hachita and Playas Valleys, as indicated by a test on one of the railroad wells near Hachita from which over 100 gallons a minute was pumped continuously during a test run of 42 hours.[8] Pumping for 12 hours at 90 gallons a minute lowered the water level 12 feet. The well is 695 feet deep and cuts four water-bearing horizons.

The depth to water in the two valleys differs considerably.[9] On the east side of Playas Valley it ranges from less than 15 feet along the bed of Playas Lake to a maximum of about 100 feet near Playas station. At Pothook station, near the northwest corner of the range, water lies at an average depth between 20 and 30 feet and only a few feet deeper than that in the wells at Hatchet Gap. In Hachita Valley, as indicated by a series of wells along or close to the axis of the valley, water lies at depths ranging from 292 feet in the railroad well mentioned above to 111 feet at Hatchet Ranch 2 miles south of Hatchet Gap, the depth to water from well to well decreasing between 10 and 11 feet to the mile. At the north end of the range the water level in Hachita Valley is at essentially the same elevation as in Playas Valley, but opposite Hatchet Gap the water level in Hachita Valley is the lower by about 100 feet. Schwennesen [10] explains this difference by supposing—and my own mapping supports his explanation—that the Big Hatchet and Little Hatchet ranges are continuous a short distance below the surface and that this buried ridge dams back the ground water of Playas Valley, preventing it from escaping through the gap into Hachita Valley. The top of the dam thus limits the height of the water table in Playas Valley. (See fig. 3.)

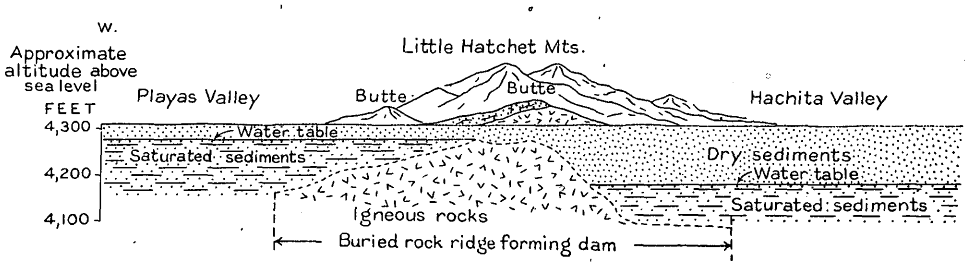


FIGURE 3.—Hypothetical section at Hatchet Gap showing underground rock barrier that separates the ground-water bodies of Hachita and Playas Valleys. After A. T. Schwennesen with geology modified by S. G. Lasky.

To judge from the few shallow mines and prospects, water level within the Little Hatchet range itself is comparatively shallow, although the depth to water differs considerably from place to place. Most wells and shafts at or near the edge of the hills reach water at depths ranging from 10 to 35 feet. Near Granite Pass a well in the granite about a mile from the alluvium has water at a depth of only 10 feet. At the Gold Hill mine water lies only 30 feet or so below the level of the ravine in which the mine is located and at about the same altitude as the spring above the Green mine just over the ridge. The Wake-Up-Charlie shaft, in the monzonite above Sylvanite camp, is dry at a depth of 100 feet, but nearby at the Handcar tunnel, 300 feet higher in the range at an altitude of about 5,700 feet, water is encountered only 40 feet below the surface. At the Buckhorn mine, 250 feet still higher and in metamorphosed sediments, water lies about 225 feet below the surface. In the Santa Maria tunnel at a point 750 feet south of Livermore Spring, water lies only a few feet below the tunnel level, or as much as 75 feet higher than the level of the spring.

In the Eureka district water level seems to lie at an altitude of 4,700 to 4,800 feet. It is 30 to more than 80 feet below the surface at the shafts on the National fault zone (pl. 21) and is 105 feet below the surface at the King 400 mine. According to Albert Fitch, 10 to 12 gallons a minute were pumped from the King 400 when he was operating on the 180-foot level. The American mine, more extensive than the King 400, is said to have pumped 125 to 150 gallons a minute from the 250-foot level, but it is further reported that at that time several of the deeper shafts in the area, including the King 400, were comparatively dry, filling to water level only when pumping was stopped at the American mine. This suggests that the American mine was draining the neighboring country through a system of fairly open channelways, and if so, pumping plants of considerable capacity may have to be installed if deep mining is ever undertaken.

The following analyses show the character of the water from different places in the area. They are indicative of the types available in connection with possible mining operations in the Little Hatchet Mountains, including water for domestic purposes, water for use in steam boilers or for cooling Diesel engines, and water for use in mills of different design that may be built to treat the different types of ore.

[8] Information from the files of the New Mexico Bureau of Mines and Mineral Resources.
[9] Schwennesen, A. T., Ground water in the Animas, Playas, Hachita, and San Luis Basins, N. Mex.: U. S. Geol. Survey Water Supply Paper 422, pp. 106–124, 1918.
[10] Idem, p. 122.

Analyses of waters from the Little Hatchet Mountains and adjacent valleys, N. Mex.[1]

[Parts per million]

No.	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Total dissolved solids
1	130	57	98	0.0	332	392	63	1,072
2	20	7.4	101	.0	209	84	29	450
3	29	5.2	128	.0	142	206	29	539
4	16	2.6	189	[2] 146		145	44	[8] 584
5	43	28	96	.0	253	151	46	617
6	73	27	46	.0	223	141	46	556
7 [4]	562	55	56	....	[5] 95	1,529	30	[6] 2,361
8 [7]	156	35	31	....	[5] 116	319	77	[8] 759

[1] Analyses 1, 2, 3, 5, and 6 are from U. S. Geol. Survey Water-Supply Paper 422; analysis 4, from the files of the New Mexico Bur. Mines; analyses 7 and 8, by International Filter Co.

[2] Carbonate and bicarbonate not differentiated.

[3] Includes 35 parts of SiO_2 and 6 parts combined Fe_2O_3 and Al_2O_3.

[4] pH = 7.0.

[5] Reported as free CO_2 and $CaCO_3$; presumably all HCO_3.

[6] Includes 34 parts of SiO_2.

[7] pH = 7.1.

[8] Includes 25 parts of SiO_2.

1. Two wells at Pothook station, Playas Valley. 2. Old Hatchet Ranch wells at Hatchet Gap, Playas Valley. 3. Railroad well at Hachita, Hachita Valley. 4. Railroad well one mile west of Hachita, Hachita Valley. 5. Eight-mile well, Hachita Valley. 6. Twelve-mile well, Hachita Valley. 7. American mine, Eureka district. 8. Last Chance shaft, Eureka district.

W. D. Collins, Chief of the Section of Quality of Water, of the Geological Survey, examined the several analyses and reported as follows:

The waters represented by analyses 2 to 5, inclusive, would generally be classed as satisfactory for all ordinary uses, but if used for feed for boilers operating at high ratings they might require some attention to prevent foaming. The water represented by analysis 6 would be classed as satisfactory for most uses, although the hardness is sufficient to be objectionable for use with soap. This water should be softened for use as boiler feed. The waters represented by analyses 1 and 8 would not ordinarily be classed as unsuitable for drinking on account of their mineral content. Neither of them would be considered fit for use with soap or for use as boiler-feed water. Even after treatment for the removal of scale-foaming substances these waters would not be suitable for boiler use because of the large quantities of sodium salts that would be left after the treatment.

The water represented by analysis 7 would generally be classed as unsuitable for any use that is at all affected by the dissolved mineral matter except possibly for drinking by stock or for irrigation. It would be impossible to treat this water so as to make it suitable for boiler feed.

Mr. Collins' statements concerning the use of the waters as boiler feed apply in general also to their use in Diesel engines. Thus, to judge from the analyses of the water from the American and Last Chance shafts, the mine waters may be considered unsuited in the raw state either for domestic use or for use in power-plant boilers or Diesel engines. The valley waters, with the possible exception of that in the vicinity of Pothook, are suitable for domestic use but only moderately more suitable for the other purposes than are the mine waters. Copies of the analyses, together with descriptions of the ores, were submitted to the Federal Bureau of Mines, and the staff of its Metallurgical Division reported that, except for the danger of pipe lines becoming plugged by incrustrations, all the waters should be suitable in the raw state for milling purposes, either in flotation plants or in cyanide or amalgamation plants designed to treat the native-gold ores of the Sylvanite district.

GEOLOGIC FORMATIONS

GENERAL SUMMARY

With minor exceptions, all the sedimentary rocks of the Little Hatchet Mountains appear to be of Trinity (Lower Cretaceous or Comanche) age, and most are as young as Glen Rose or late Trinity age. The exceptions include only the Quaternary alluvium and a little material associated with the Tertiary pyroclastic rocks, and possibly an isolated exposure of uncertain age in Hatchet Gap. Magdalena limestone is exposed in the southernmost hill at Hatchet Gap and constitutes a geologic link with the Big Hatchet Mountains, which consist almost entirely of Paleozoic rocks. Interbedded with the sedimentary rocks of the Little Hatchet Mountains are basaltic lava flows and pyroclastic material, and at one place is a small body of orthoclase gabbro that may be the intrusive equivalent of some of the lava. These rocks and their structural relations are shown on plates 1 and 2.

The Lower Cretaceous volcanic rocks and the enclosing sedimentary rocks are intruded by diorite sills and by later stocks. Three of these stocks are exposed—a small monzonitic mass west and south of Old Hachita, a composite mass of monzonite and quartz monzonite at Sylvanite, and a composite granite mass between Granite Pass and Hatchet Gap—though the small cropping at Old Hachita appears to be the faulted top part of the mass at Sylvanite. Each of the three stocks is bordered by a contact-metamorphic halo, and each is accompanied by its satellite dikes; monzonite porphyry dikes are particularly prominent with the stock at Old Hachita, lamprophyre dikes with that at Sylvanite, and aplite dikes with that at Granite Pass. There seems to be a closer genetic connection between these rocks and the ore deposits of the range than is ordinarily observable in mining districts.

The intrusive rocks of this group are broadly referred to hereafter as of late Cretaceous or early Tertiary age, as a way of indicating only that they are known to be younger than the Lower Cretaceous formations and older than the Miocene(?) volcanic rocks mentioned in the following paragraph. So far as evidence within the Little Hatchet Mountains alone is concerned, they may be any age from late lower Cretaceous to early Tertiary, but by analogy with the Santa Rita area,[11] which has an almost

[11] Spencer, A. C., and Paige, Sidney, Geology of the Santa Rita mining area, N. Mex.: U. S. Geol. Survey Bull. 859, 1935. Lasky, S. G., Geology and ore deposits of the Bayard area, Central mining district, N. Mex.: U. S. Geol. Survey Bull. 870, 1936.

identical igneous history (p. 40), the oldest of the group, the diorite sills, would seem to be at least as young as late Upper Cretaceous.

A fringe of Tertiary volcanic rocks, chiefly fragmental, overlies the beveled and eroded outcrops of the earlier formations at the extreme north and west-central parts of the range, and the Coyote Hills consist almost entirely of such rocks locally interbedded near the base with lenses of conglomerate. These rocks are part of the Mexico-Arizona-New Mexico lava field, whose age is generally presumed to be Miocene. For southeastern Arizona and the adjacent part of New Mexico an upper limit for their age is given by the fact that the tilted volcanic rocks are overlain by valley fill that in part is upper Pliocene.[12]

Dikes and sills of latite and felsite, all later than the ore deposits, crop out at several places. Some are probably later than the Miocene(?) pyroclastic rocks, others are earlier, but all are believed to be closely related genetically. Dikes of granite, apparently younger than the Miocene (?) rocks, occupy places along the Copper Dick fault.

Small masses of basalt, presumably representative of the Pleistocene flows, cut the Miocene(?) rocks, and the entire bedrock assemblage is surrounded by alluvium of Pliocene to Recent age. Isolated patches of gravel, which indicate an alluvial fan of probable late Pleistocene age, appear here and there within the range.

In the following pages the geologic formations are described as consistently as possible in chronologic order, but in the paragraphs immediately below, the sedimentary and igneous rocks are summarized separately. The igneous metamorphism of the rocks is described in a separate section. (See pp. 55-61.)

SUMMARY OF THE SEDIMENTARY ROCKS

STRATIGRAPHY

The Lower Cretaceous rocks have been divided in this investigation into seven formational units, to which local names have been given.[13] These are, in ascending order, the Broken Jug limestone, the Ringbone shale, the Hidalgo volcanics, the Howells Ridge formation, the Corbett sandstone, the Playas Peak formation, and the Skunk Ranch conglomerate. Their aggregate exposed thickness ranges from 17,000 to 21,000 feet, with the base of the section covered by valley fill. The formational limits were placed as uniformly as possible at disconformities[14] or at horizons of prominent lithologic change, each formation representing a particular set or cycle of depositional conditions. Five disconformities have been recognized, but only one is continuous throughout the area. Deposition appears to have taken place along and near an oscillating shore line so that a disconformity representing the removal of a considerable thickness of older rocks at one place becomes a conformable contact at another. (See pls. 3 and 13(1).)

With the exception of the Ringbone shale, Hidalgo volcanics, and Skunk Ranch conglomerate, the same sequence of rocks crops out in the southern part of the range as in the northern part, the formations having been duplicated by the Copper Dick fault. The area north of the fault is here called the Eureka section and the area south of it the Sylvanite section. The Hidalgo volcanics are missing from the Sylvanite section because of one of the disconformities (see pl. 13(1)); the Ringbone shale is missing because it was deposited in a local basin that did not extend to the south; and the Skunk Ranch conglomerate, or its offshore equivalent, is missing because it has been cut out by one of the stocks. Plate 3 shows the comparative stratigraphy of the Eureka and Sylvanite sections, and the table on page 13 summarizes the general stratigraphy of the range.

The total thickness of the Lower Cretaceous formations listed in the above table ranges from 10,200 feet, obtained by adding minimums, to 26,525 feet, obtained by adding maximums. The actual total thickness exposed in a continuous section in the Eureka area, however, is from 17,000 to 21,000 feet, the thickest part of some formations being opposite the thinnest part of others (see pl. 13(1)), and in the Sylvanite area the actual total exposed thickness is about 15,300 feet. The aggregate thickness of Lower Cretaceous volcanic rocks is as much as 5,700 feet.

AGE

The fossils collected from the different formations are listed in the accompanying table, and the geographic distribution of the collections is shown on plate 12. The ammonites included in the list were studied and described by Prof. Gayle Scott,[15] and the rest of the identifications were made by T. W. Stanton, J. B. Reeside, Jr., and L. G. Henbest of the Geological Survey.

Plate 3 shows the detailed stratigraphic distribution of the different forms. The general assemblage seems much the same throughout the sequence, but with a repetition of particular forms at several horizons, accompanied by a repetition of zones of similar or identical lithology. There are four zones of massive limestone—perhaps of reef origin (p. 52)—containing crowded colonies of the foraminifer *Orbitolina*, the mollusks *Toucasia* and rudistids, and perhaps less commonly the large gastropod *Tylostoma;* four coquina zones containing *Exogyra quitmanensis* Cragin and a large unnamed *Pecten;* two horizons containing the ammonite *Douvilleiceras;* repeated but less distinct and less critical zones with the gastropod *Turritella;* and two or three zones containing fresh-water mollusks and fossil wood. The significant forms identified are *Exogyra quitmanensis*, the large unnamed *Pecten*, which Stanton says is characteristic of Taff's "Quitman bed,"[16] *Orbitolina*, and the ammonites *Douvilleiceras* and *Trinitoceras reesidei* Scott.[17] These are Trinity

[12] Knechtel, M. M., Geologic relations of the Gila conglomerate in southeastern Arizona: Am. Jour. Sc., 5th ser., vol. 31, pp. 81–91, 1936.

[13] Lasky, S. G., Newly discovered section of Trinity age in southwestern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 22, pp. 524–540, 1938.

[14] As used here, the term disconformity is defined as an unconformity in which the beds above the erosion surface are parallel to those below.

[15] Scott, Gayle, Cephalopods from the Cretaceous Trinity group of the south-central United States: Texas Univ. Pub. 3945, pp. 969-1106, 1940.

[16] Taff, J. A., The Cretaceous deposits [of El Paso County, Texas]: in the Texas Geol. Survey Ann. Rept., pp. 714–738, 1891.

[17] Scott, Gayle op. cit.

Sedimentary and other layered rocks exposed in the Little Hatchet Mountains, New Mexico

Age		Formation and member			Thickness (feet)		Lithology and remarks
Quaternary.	Recent to Pleistocene.	Valley fill.			836+		Generally unconsolidated gravel, sand, and clay filling the valleys that surround the range. Some lake deposits.
Quaternary.	Pleistocene.	High alluvium.			0–20±		Unconsolidated gravel perched above present arroyos and forming a thin apron over comparatively large areas. Related to an old drainage level 20 to 30 feet above the present one.
		Angular unconformity					
Tertiary (Miocene?).		Lava flows.			300+		Latite and quartz latite flows.
Tertiary (Miocene?).		Pyroclastic rocks.			200–1,700		Rhyolitic breccias and tuffs, including some "welded" material. Includes minor layers of volcanic sand and gravel and, locally, lenses of conglomerate.
		Angular unconformity					
Cretaceous (?).		Quartzite and limestone of uncertain age.			0–275		Patches of white quartzite and overlying sandy limestone capping the Granite Pass stock in the isolated hills at Hatchet Gap.
Lower Cretaceous (Comanche).	Trinity(?).	Bisbee group.	Skunk Ranch conglomerate.		2,100+	3,400	Only in the Eureka section. Chiefly red and maroon conglomerate with a matrix of red sandstone and shale. Includes much clay shale, mostly red, and some soft sandstone. In upper part the boulders seem to be Paleozoic, but in lower half only Lower Cretaceous rocks were recognized. At one place contains a layer of augite basalt.
				Volcanic member. (*Map unit*)	0–200		
					500–1,100		
			Disconformity				
Lower Cretaceous (Comanche).	Trinity.	Bisbee group.	Playas Peak formation.		800–3,000+		Predominantly green and brown fresh-water shale and light-colored sandstone and grit; locally with basal conglomerate and capped by massive fossiliferous reef-like marine limestone.
			Disconformity (local)				
			Corbett sandstone.		1,500–4,000		Sandstone, partly quartzitic and massive, with subordinate thin members of sandy shale. Several thin members of limestone in Eureka section containing marine fauna.
			Howells Ridge formation.	Top limestone member.	200–545	1,100(?)–5,200(?)	Massive and thin-bedded black limestone and massive crystalline creamy-white limestone; fossiliferous and reef-like in Eureka section, where this member is thickest and forms a prominent cliff.
				Volcanic member. (*Map unit*)	0–400		Only in Eureka section locally. Chiefly augite andesite flows, elsewhere purple volcanic breccia grading laterally into purple shale and volcanic grit. Varies stratigraphically from just beneath top limestone member to about 150 feet below it.
					600(?)–4,700±		Commonly red beds of shale, sandstone, limestone, and conglomerate, interbedded and gradational.
			Disconformity				
			Hidalgo volcanics.	Sedimentary member. (*Map unit*)	0–200+	0–5,000+	Only in Eureka section, where 900 to 5,000 ft. are exposed; topmost part cut out by fault. Almost entirely basic flows; some pyroclastic rocks. Most flows basaltic, the rest andesitic. In upper part, locally includes a sedimentary member composed of limestone, shale, and gritty or conglomeratic layers, with associated flow-streaked felsite; felsite-sedimentary horizon partly cut out by disconformity beneath Howells Ridge formation.
			Disconformity				
			Ringbone shale.		0–75	0–650±	Only in Eureka section. Black and green fissile shale, subordinate sandstone, and a little black limestone. Fresh-water beds. Includes a basalt flow and a layer of andesite breccia, with associated tuffaceous sandstone and shale. Locally disconformable, with basal conglomerate, on the Broken Jug.
				Volcanic members. (*Map units*)	25–100		
					0–475±		
			Disconformity (local)				
			Broken Jug limestone.		3,400–5,000(?)		Limestone, pure, shaly, and sandy, and interbedded sandstone and limestone conglomerate; considerable local variation. In Eureka area contains a persistent coquina bed and is commonly capped by massive fossiliferous reef-like limestone forming a prominent bluff. Locally overlain disconformably by Ringbone shale, but elsewhere the caprock grades laterally into conglomerate conformable with Ringbone and disconformable with underlying beds of Broken Jug. Base of formation concealed by Quaternary valley fill.
					Concealed interval		
Carboniferous.	Pennsylvanian.	Magdalena limestone.			1,400		Fossiliferous limestone. Upper part contains fusulinids found elsewhere in New Mexico about 1,000 feet above the Mississippian.

Fossils from the Little Hatchet Mountains, New Mexico

Formation	Magdalena limestone	Broken Jug limestone																			Ringbone shale					Howells Ridge formation								Corbett sandstone		Playas Peak formation							Skunk Ranch conglomerate
U. S. National Museum Collection No.	LH-191-34	17362	16926	16927	LH-3-34	LH-25-34	17434	17432	16955	17364	17435	LH-4-34	16962	17438	17436	17359	17361	17437	17439	17440	JBR-16	16928	16958	16957	JBR-17	LH-75-34	16956	17443	17442	16963	17441	16959	LH-184-34	17445	17444	16961	17446	LH-86-34	16960	17447	17433	LH-130-34	LH-101-35
Map No. (Pl. 12)	43	4	5	6	7	8	9	10	11	12	13	14	15	19	20	21	23	24	25	26	1a	1	2	3	3a	16	17	27	28	29	31	34	35	32	33	18	36	37	38	39	40	42	41
Foraminifera:																																											
Orbitolina aff. *O. texana* Roemer and *O. walnutensis* Carsey					X							X																															
Orbitolina texana Roemer		X															X									X												X				X	
Orbitolina sp.					X	X						X																					X										
Triticites beedei Dunbar	X																																										
Triticites secalicus Say	X																																										
Corals:																																											
Corals							X							X														X															
Echinoderms:																																											
Echinoids							X	X			X					X			X																								
Brachiopods:																																											
Brachiopods														X				X																									
Worms:																																											
Worm tubes[1]																															X												
Serpula sp.																			X																								
Pelecypods:																																											
Arca? sp.													X																														
Arctica cf. *A. medialis* (Conrad)																																			X								
Arctica sp.															X				X																								
Exogyra quitmanensis Craigin									X											X									X	X	X									X			
Gryphaea sp.																			X																								
Lima sp.								X											X																								
Neithea occidentalis (Conrad)																			X																X								
Ostrea (*Exogyra?*) sp.				X																										X													
Ostrea sp.			X																																								
Ostreids																																		X									
Pecten n. sp.									X											X									?		X												
Protocardia texana Conrad				X																																							
Protocardia sp.											X				X																				X								
Protocardia? sp.													X																														
Rudistids														X																													
Toucasia texana (Roemer)?																																							X				
Toucasia sp[1]																																					X						
Toucasia? sp.																											X																
Trigonia sp.																			X																X								
Unio sp.																																				X					?		
Gastropods:																																											
Amauropsis? cf. *A. pecosensis* Adkins																																								X			
Fusus? sp.																														X													
Nerinea sp.																																		X									
Planorbis sp.																																				X					X		
Physa sp.																						X		X												X							
Turritella cf. *T. seriatimgranulata* Roemer																														X													
Turritella sp.																																		X									
Tylostoma cf. *T. mutabilis* Gabb																																X											
Tylostoma sp.																			X																X								
Tylostoma? sp.																																		X									
Viviparus sp.																																				X							
Viviparoids																							X																				
Ammonites:																																											
Beaudenticeras hatchetense Scott, n.sp.																			X																								
Douvilleiceras n.sp.													X																														
Douvilleiceras sp.								X																																			
Trinitoceras reesidei Scott, n.gen.n.sp.										X									X																								
Plants[2]																																											
Algae																																											X
Fossil wood[3]																					X				X																		

[1] Noted in the field in the Broken Jug limestone; no collection made.
[2] Vegetable debris noted in the field in the Ringbone shale; no collection made.
[3] Fossil wood noted in the field in the Broken Jug limestone and Playas Peak formation; no collection made.

forms. Stanton reported that he had "no hesitation in referring the several lots containing *Orbitolina* to rocks of Glen Rose (upper Trinity) age," and the *Douvilleiceras* in this association apparently indicates lower Glen Rose age.[18] Concerning the entire assemblage, Reeside reported "all these belong to the general Glen Rose fauna." Consequently the entire section from the *Orbitolina* zone at the top of the Playas Peak formation to the lower *Orbitolina* zone of the Broken Jug limestone is of Glen Rose age, and the fact that *Exogyra quitmanensis* zones are sandwiched between *Orbitolina* zones suggests that the Glen Rose interval may extend at least down through the lower *Exogyra* beds of the Broken Jug limestone. Inasmuch as no notable lithologic break is exposed below the lowest *Exogyra* beds, the basal beds also of the Broken Jug limestone may be of Glen Rose age, and they are presumed to be at least as young as Trinity.

As indicated in the table on page 14 and on plate 3, the only fossils found in the Skunk Ranch conglomerate, above the Playas Peak formation, are some algal deposits, which at present have no age significance, but for reasons given in the description of the Skunk Ranch conglomerate, it also is presumed to be of Trinity age.

CORRELATION

The repetition of faunas and lithologic units in the Little Hatchet Mountains, the lateral changes in lithologic character, and the fact that neither the upper nor lower limits of the Trinity section are exposed, or at least not identifiable, make any regional correlation between individual sedimentary formations of the Little Hatchet Mountains and other formations of Trinity age impossible at present.

The section is roughly equivalent to part of the Bisbee group of southeastern Arizona, in that the Mural limestone of the Bisbee group also is of Trinity age,[19] but the problem has turned out to be more difficult than indicated by Darton's statement that his Comanche "limestones of the Hatchet Mountains region closely resemble the Mural limestone of the Bisbee and Douglas regions, Arizona, to which they doubtless are equivalent."[20] The limestone of Comanche age that Darton recognized in the Little Hatchet Mountains is the cliff-making *Orbitolina*-bearing member at the top of the Howells Ridge formation.[21] That member does, it is true, resemble the cliff-making *Orbitolina*-bearing Mural limestone, but the other *Orbitolina* limestones in the Little Hatchet Mountains are to all appearances identical in lithologic character and fauna with the Howells Ridge *Orbitolina*-bearing member, and any one of them, or conceivably none of them at all, could equally well be the equivalent of the Mural. Moreover, other parts of the Howells Ridge formation resemble both the Morita and Cintura formations[22] of the Bisbee group, one below the Mural limestone and the other above it, and some reddish beds in the Broken Jug limestone also might be duplicated in the Morita and Cintura formations.

Darton's "Sarten sandstone" in the little Hatchet Mountains, in his map unit "Sarten sandstone and underlying limestone" of Comanche age,[23] is the formation called the Corbett sandstone in this report. The reasons for dropping the name Sarten and choosing a local name in its place are given in the description of the Corbett sandstone.

Correlation of the volcanic rocks of Trinity age with pre-Tertiary volcanic rocks in neighboring areas is discussed under the heading, Hidalgo volcanics. (See p. 21.)

SUMMARY OF THE IGNEOUS ROCKS

The igneous rocks of the Little Hatchet Mountains include 22 varieties, considering the pyroclastic rocks as igneous, which are grouped under 18 text headings and map units. The petrographic features of these rocks, as determined from 6 chemical analyses and 73 thin sections, are summarized graphically on plate 4. Shown there also are the geologic ages of the rocks and their age relation to the period of ore formation and to later stages of barren mineralization; the form of the rock masses is noted with their petrographic names. Except that the monzonite dikes and sills have been placed next the composite rock masses to which they are satellite, the rocks are arranged in chronologic order as nearly as information and the mechanical restrictions of the summary permit. For example, there is no factual evidence that the Granite Pass stock is later than the stocks at Sylvanite and Old Hachita. Similarly, the age relationship between aplite and lamprophyre dikes is not invariable, nor is the exact relation between the felsite and all the latite dikes known. The exact age and affiliation of the orthoclase gabbro also are uncertain.

The chart as drawn shows a distinct petrographic trend for the rocks of the Little Hatchet Mountains, but it must be recognized that there is a weakness in this picture in the assumed position of the Granite Pass stock in the sequence; for if the Granite Pass stock were placed before the Sylvanite and Old Hachita stocks the orderly petrographic trend would be broken. Assuming, however, that it is more reasonable to place the granite later in the sequence than the monzonite and quartz monzonite, rather than earlier, then the rocks of the area would appear to represent an orderly differentiation sequence, at least as far as the close of the late Cretaceous or early Tertiary stage; the right-hand side of the chart shows a trend back toward the basic end, but, because of the irregular sequence commonly shown by Tertiary lavas and the fact that only the earliest of the Tertiary rocks are exposed in the Little Hatchet area, the significance of the right-hand side of the chart is questionable. It should be noted that the variations in the composition of the plagioclase feldspar roughly parallel those in the mineral content, becoming progressively more sodic not only as the proportion of felsic minerals as a group increases

18 Sellards, E. H., Adkins, W. S., and Plummer, F. B., The geology of Texas, vol. 1: Texas Univ. Bull. 3232, p. 260, 1932.

19 Ransome, F. L., The Geology and ore deposits of the Bisbee quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, pp. 65–68, 1904.

20 Darton, N. H., "Red beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 38, 1928.

21 Oral communication.

22 Ransome, F. L., op. cit.

23 Darton, N. H., U. S. Geol. Survey Geologic Map of New Mexico, 1928.

and the mafics decrease, but also paralleling variations within the felsic group. There is also a progression of the mafic constituents from the augite-olivine end to the biotite end, such as would be demanded theoretically and as is supported by the microscopic evidence that some later mafic minerals were formed by reaction with earlier. The lamprophyre dikes are at variance with the orderly progression shown by the other rocks, but that is a characteristic of lamprophyres in general.

The insert of plate 4 shows a comparison between the mineralogic variations of the most important rock masses of the Little Hatchet Mountains and similar variations in the average rocks of the principal rock clans.[24] Evidently the Little Hatchet rocks as a group are low in the mafic minerals. Chemical analyses suggest that a high P_2O_5 content also is a family trait for the rocks of the Little Hatchet Mountains, for in all except two analyses of monzonite the P_2O_5 content is 2 to 3 times as great as in Daly's averages. A further family trait may be an abnormal content of TiO_2, as indicated by most of the analyses and by the general prominence of sphene in all rocks, but there is some possibility that part of the TiO_2 was introduced during metamorphism. (See (p. 57.)

Both the porphyritic granite facies of the Granite Pass stock and the monzonite facies of the Sylvanite stock are in part the result of replacement of the sedimentary rocks, but that fact would seem to have no real effect on the situation depicted above, for if only a minute portion of each of those rocks were the result of igneous injection the petrographic trend would still be the same. Some credence may be lent to the possibility that the porphyritic granite is entirely a replacement rock, but even so the picture still would not be much changed.

PRE-CRETACEOUS ROCKS

MAGDALENA LIMESTONE

The southernmost hill at Hatchet Gap is composed of Magdalena limestone, of Pennsylvania age, faulted against the Granite Pass stock at the north end of the hill. The topmost beds of the exposure contain fusulinids identified by L. G. Henbest as *Triticites beedei* Dunbar and *T. secalicus* (Say). Needham[25] lists neither of these forms in his bulletin on New Mexico fusulinidae, but he has told me informally that the species *T. beedei* suggests, in southwestern New Mexico, a horizon about 900 or 1,000 feet above the base of the Magdalena.

LOWER CRETACEOUS ROCKS

BISBEE GROUP

BROKEN JUG LIMESTONE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Broken Jug limestone, named after Broken Jug Pass, west of Sylvanite, is the oldest formation exposed in the Little Hatchet Mountains proper. It is present in both the Eureka and Sylvanite parts of the range. In the Eureka section it makes up the chain of hills and ridges that front the northeast corner, beginning at a point about a mile north of Howells Wells and extending northward to a point near Old Hachita, whence it bends northwestward, the outcrop widening as it does so. In the Sylvanite section the formation occupies several square miles on the east side of the range and forms the steep and ravined scarp of the Copper Dick fault. It is cut off on the west by the Sylvanite stock, and its resistant metamorphosed parts next to the stock are responsible for the height of Hachita Peak. Inclusions or pendants of it crop out at several places in the stock.

STRATIGRAPHY

The Broken Jug limestone is highly variable from place to place, but in general the formation consists of pure, shaly, and sandy limestone, interbedded with shale, sandstone, and conglomerate. In places pure limestone predominates, elsewhere shaly or sandy limestone associated with considerable sandstone. Conglomerate is prominent locally.

The lowermost part exposed in the Eureka section crops out on the ridge and pediment extending from Old Hachita eastward into sec. 31. On the south side of the ridge and on the crest the beds consist chiefly of sandstone, massive to thin-bedded and generally limy or shaly, and containing streaks of chert conglomerate. Limestone and subordinate shale are present. Northwestward along the strike the conglomerate becomes coarser and more abundant, limestone pebbles appear, and the intervening sandy and shaly beds are more limy. In the Copper King shaft and on the Copper King and Esmeraldo claims (pl. 20), the formation contains much red to greenish mudstone or shale. Similar beds crop out just to the north where the Hachita road meets the valley fill (pl. 5), and red soil at the east end of the Howard vein indicates similar rock there.

North of the Hachita road the formation consists largely of limestone conglomerate, individual beds ranging from sandstone containing only a few small pebbles of chert and limestone to tightly packed masses of limestone cobbles and pebbles 4 inches or less in diameter. Fragments of crinoid stems were recognized in some of the pebbles. Included in this part of the formation is an indistinct 80-foot coquina zone, and well above it is a second and stronger coquina zone composed of oyster beds 2 to 10 feet thick separated by less fossiliferous layers. The upper zone is persistent and easily recognizable and constitutes a useful horizon marker. (See pl. 5.) Above the main coquina beds are several hundred feet of fossiliferous *Orbitolina*-bearing limestone that constitutes the top member of the formation over most of the Eureka area. It forms the main hills of this belt, including the Last Chance and Hornet hills—the two limestone hills at the east edge of sec. 1, at the Last Chance and Hornet claims—and the more prominent bluff just north of Old Hachita.

The two small areas of Broken Jug limestone in secs. 12 and 18 south of the Hornet mine are in a higher part of the formation than is exposed elsewhere, but their isolated position precludes any real estimate of their exact stratigraphic position. The

[24] Grout, F. F., Petrography and petrology, pp. 88, 125–26, McGraw-Hill Book Co., 1932.

[25] Needham, C. E., Some New Mexico fusulinidae: State Bureau of Mines and Mineral Resources, New Mexico School of Mines Bull. 14, 1937.

lowest part consists of *Orbitolina*-bearing limestone like that forming the hills to the north; next above are some shaly beds, including some red beds, and then a thick section of oyster beds. Massive *Orbitolina*-bearing limestone overlies the oyster beds and at one place is in turn overlain by more red beds.

The following measured section shows the character of the formation in the vicinity of Old Hachita.

Section of Broken Jug limestone north of King 400 mine, Eureka district

[Begins at valley fill at east end of King vein outcrop, on north side of vein, and ends at point near NW. cor. sec. 36]

	Feet
Basal conglomerate of the Ringbone shale.	
Disconformity.	
Broken Jug limestone:	
Limestone, medium to dark gray. Upper part massive, lower part thinner-bedded in layers 3 feet thick or less. *Orbitolina* zones throughout. *Toucasia* prominent locally in upper massive part; ammonite horizon in lower thin-bedded part. Includes two diorite sills, respectively 63 and 160 feet thick on line of section, just above thin-bedded part	769
Concealed	51
Sandstone, brown, generally limy. A persistent bed	11
Coquina zone. Oyster beds 2 to 10 feet thick, composed almost entirely of large *Exogyra* as much as 7 inches in diameter, interlayered with less fossiliferous beds. *Pecten* zone. An excellent horizon marker in the main part of the Eureka district	189
Limestone, medium gray, in beds 1 to 5 feet thick; argillaceous patches in upper few feet	39
Sandstone, light gray	14
Limestone, gray, with argillaceous patches	42
Limy sandstone, gray, weathering buff	13
Conglomerate, white, fine-grained; mostly pebbles of sandstone	5
Limestone, gray, dense, weathering pitted and brown; 6 feet of sandy limestone at base	38
Limestone, shaly, weathering brown, with purer parts remaining as rounded gray patches	51
Sandstone, white to light gray, in beds about 10 feet thick; contains conglomeratic streaks and is locally coarse-grained; very limy in places	41
Limestone, gray, sandy, weathering buff	34
Shaly limestone, dark gray, dense; upper part purer	27
Sandstone, gray, limy	12
Sandstone, white, coarse-grained, containing streaks of conglomerate; pebbles include limestone and gray to white chert	9
Sandstone, gray, with limy and fine-grained conglomeratic streaks; basal 3 feet is a fine-grained conglomerate; pebbles are limestone and chert	59
Limestone, gray, containing argillaceous patches and stringers that weather out	32
Limy sandstone, dark gray	50
Limestone conglomerate with subordinate chert pebbles; matrix is sandstone and is subordinate to pebbles	12
Limy sandstone, dark gray, weathering buff	78
	1,576
Valley fill.	

The thickness of the above section, exclusive of the diorite sills, is 1,353 feet.

To the north of the limestone bluff north of Old Hachita the Broken Jug limestone is largely covered with wash, in part by an apron of high alluvium, but it appears to differ decidedly from the part to the south. A bed of *Orbitolina*-bearing limestone crops out here and there and apparently belongs to the same member as that forming the bluff; it seems to be only about 60 feet thick, however, and this rapid thinning of the *Orbitolina* member appears to be accompanied by an accordant decrease of limestone in the underlying beds and an increase in shale. The 60-foot limestone bed is traceable northwestward for more than a mile to a point near the hill east of the Ringbone ranch on which the airplane beacon is built, where it merges into a conglomerate bed. At the road fork at the foot of the beacon hill this conglomerate bed is only 5 feet thick, but just north of the fork it abruptly thickens to make up the whole of the hill, as well as most of the isolated ridges northeast. The small exposures at the north edge of the apron of high alluvium also consist chiefly of the conglomerate, which is doubled back on the north flank of the Vista anticline.

In detail the beacon hill consists of conglomerate layers interbedded with subordinate sandstone. The basal part is unsorted and contains boulders as much as 2 feet in diameter (pl. 8, *A*); the extreme upper part contains bodies of massive *Orbitolina*-bearing limestone as much as 10 feet across that seem to be cementing material rather than foreign boulders. Pebbles and boulders of Lower Cretaceous rocks only were identified in the conglomerate. They are evidently of local derivation and include limestone, sandstone, and earlier conglomerate, many beds being composed chiefly of one kind. The beds forming the hill must aggregate at least a thousand feet in thickness.

The Broken Jug limestone in the Eureka half of the range is in part conformable, in part disconformable, with the next younger formations, a disconformable contact at one place passing into a conformable contact elsewhere. The conglomerate at the beacon hill, though continuous stratigraphically with the *Orbitolina*-bearing limestone that forms the bluff at Old Hachita, is disconformable with the underlying beds but interfingers with the sandstone beds of the overlying Ringbone shale. To the southeast, on the contrary, the limestone of the bluff is separated from the Ringbone shale by a disconformity that cuts down at Old Hachita nearly to the oyster beds. South of Old Hachita the disconformity again rises in the section, and at the isolated exposures south of the Hornet mine it forms the contact between the upper oyster and *Orbitolina*-bearing beds and the Hidalgo volcanics, which immediately overlie the Broken Jug limestone in that part of the Eureka area. The maximum relief of the disconformity, as indicated by the stratigraphy, may therefore be well over 2,000 feet; the height of one of the old hills on this surface was measured at about 325 feet.

The Sylvanite section of the Broken Jug limestone, south of the Copper Dick fault, consists predominantly of massive to thin-bedded shaly and sandy limestone. Considerable light-colored limy sandstone is present in the lower part of the exposed section, and conglomerate beds like those of the Eureka section are present throughout. The following section illustrates the character of the formation in the Sylvanite part of the range; not detailed in the section are many generally thin sills and dikes related to the Sylvanite stock and aggregating about 400 feet in thickness.

Composite section of Broken Jug limestone east of Broken Jug Pass

[Begins at valley fill in sec. 30, at meridian 108°25′, dip 34°NW., and ends at point near east edge of sec. 2, dip 54°SW. Lower two-thirds of section measured by R. F. Pettit]

	Feet
Metamorphosed maroon shale of the Howells Ridge formation.	
Disconformity (?).	
Broken Jug limestone:	
Limestone, black, sandy to shaly, with layers and streaks of limy shale. Some layers intensely metamorphosed. Includes a 13-foot bed of metamorphosed flow-streaked conglomerate 81 feet from the top	349
Conglomerate, metamorphosed and flow-streaked	26
Limestone, black, shaly, some parts sandy and light gray, containing occasional layers of quartzite 1½ feet or less thick in upper part. Upper 100 feet metamorphosed locally	255
Concealed	23
Sandstone, limy, and limestone, shaly and sandy, interbedded	44
Limestone, black and shaly with sandy streaks in lower half; gray and sandy, passing locally into limy sandstone, in upper half. Faint metamorphism in some layers. Lower half includes two conglomerate members, 11 feet and 26 feet thick, in its lowermost part	520
Shale, black, sandy, including sandy limestone layers 6 inches or less thick	19
Limestone, black and shaly and with local conglomerate in lower part; dark gray and sandy in upper part. Shaly parts partly metamorphosed	53
Sandstone, dark, in part brown and thin-bedded	117
Limestone, blue, containing a few chert pebbles	63
Sandstone, dark, shaly, containing, near the middle, 50 feet of cleaner brown sandstone overlain by 10 feet of blue limestone	232
Concealed	218
Sandstone, brown to gray; 1-foot conglomerate bed near center	143
Conglomerate	99
Sandstone, brown in lower part, blue-gray in upper part, which passes laterally into conglomerate	78
Conglomerate	130
Sandstone, nearly white to brown, limy in lower 75 feet; weathers yellow	727
Limestone, blue, sandy, including a 9-foot sandstone member in middle third	60
Limestone, sandy, lower half blue, increasingly sandy upward and grading into brown limy sandstone at the top	231
Sandstone, fine-grained, limy	9
Valley fill.	3,396

As indicated in the section, the Broken Jug limestone in the Sylvanite half of the range is overlain directly by the Howells Ridge formation, which in the Eureka area is separated from the Broken Jug limestone by the Ringbone shale and Hidalgo volcanics. No obvious disconformity was recognized, however, and the contact was chosen at the first red or purple beds of the Howells Ridge formation. It is not considered likely that the Broken Jug limestone as thus mapped includes any beds that could be assigned to the Ringbone shale; conceivably the upper part might be equivalent to the Ringbone, but the first reasonable dividing plane is nearly 1,500 feet below the top as mapped in contrast with a maximum thickness of only 650 feet for the type Ringbone shale in the Eureka section. The known lithologic variations in the Broken Jug limestone in the Eureka area and its local conformable relation to the Ringbone shale suggest that the Broken Jug and Ringbone formations might elsewhere be undifferentiable, but it seems more probable that the Ringbone shale thinned out by overlap against the Broken Jug limestone, as described in the paragraphs on the stratigraphy of the Ringbone shale, and never extended this far south.

On the other hand the Broken Jug limestone might properly include some of what is mapped as Howells Ridge formation, for thin-bedded reddish sediments indistinguishable from parts of the Howells Ridge formation are present at several horizons in the Eureka part of the Broken Jug. However, the horizon arbitrarily chosen as the contact between the two formations seems to be the most practicable one that can be selected.

The total thickness of the Broken Jug limestone is not known, for the base of the formation is nowhere exposed. In the Sylvanite half of the range the maximum exposed thickness, exclusive of a variable thickness of sills, is about 3,400 feet. In the Eureka half the exposed thickness may be as much as 5,000 feet or more; the figure is uncertain because the beds in the lowest part of the formation, on the ridge and pediment east of Old Hachita, are disturbed by numerous small faults and tight folds whose net effect is difficult to evaluate. Moreover, the figure may have to be augmented, depending on hidden structure, by the thickness of beds covered by the wide stretch of wash between the Hornet mine and the isolated exposures to the south.

FAUNA

Several lots of fossils have been collected from the Eureka part of the Broken Jug limestone. (See pls. 3 and 12.) The most abundant and widespread form is a large high-coned variety of *Orbitolina*, as much as a centimeter in diameter, which is present at several horizons throughout the extent of the massive limestone members. It is particularly abundant at the limestone hills near the Last Chance claim and Hornet mine. The intervening parts of the limestone, between individual *Orbitolina* horizons, almost invariably contain large calcitized forms whose cross sections suggest a species of *Toucasia* and others whose cross sections indicate rudistids. Speciments of *Douvilleiceras* were found at three places near Old Hachita, apparently at the same horizon in the lower part of the lower *Orbitolina* zone, and specimens of ammonites, including *Beudanticeras hatchetense* Scott n. sp., and *Trinitoceras reesidei* Scott n. gen. n. sp.,[26] seem abundant in a thin limestone layer above the *Orbitolina* beds at fossil locality 25. The main oyster beds, the marker horizon, were found to consist largely of *Exogyra quitmamensis* Cragin, accompanied at places by a large *Pecten*. (See pp. 12, 14.) The *Exogyra* is also the principal form in the upper oyster beds and is accompanied there, too, by the *Pecten*.

RINGBONE SHALE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Ringbone shale, a formation named after the Ringbone Ranch, near which it is best exposed, includes all the beds between the Broken Jug lime-

[26] Scott, Gayle, Cephalapods from the Cretaceous Trinity group of the south-central United States: Texas Univ. Pub. 3945, pp. 696–1106, 1940.

stone and the Hidalgo volcanics. It is recognizable only in the Eureka section, and the main part of its outcrop forms a band about a mile wide crossing the low foothills of the dissected pediment at the north edge of the range. The northwest end of this band passes under the fill of Playas Valley, but some exposures crop out farther north at the edge of the Tertiary volcanic rocks that constitute the Coyote Hills. The outcrop narrows sharply a mile northwest of Old Hachita, and from there southward to the point where it thins out altogether near the Hornet mine, the outcrop has an average width of only a few hundred feet and lies between rocks sufficiently more resistant to control the topography.

STRATIGRAPHY

As indicated in the description of the Broken Jug limestone, the contact between that formation and the Ringbone shale is conformable along the north part of the Ringbone outcrop. Near the place where the Ringbone outcrop narrows so abruptly, however, the contact becomes disconformable and remains so to the southernmost point of the formation.

A basal conglomerate having a maximum thickness of about 115 feet partly fills in the hollows of the disconformity. (See pl. 8, *B*.) It is much like the conglomerate member of the Broken Jug limestone at the beacon hill near the Ringbone ranch and includes pebbles and boulders of sandstone, earlier conglomerate, limestone, and coquina, all of which could have been derived from the underlying Broken Jug strata. Boulders a foot in diameter are common, and some are as much as 2½ feet across. The rest of the formation consists of black and green fissile shale, some of it containing vegetable debris, subordinate fine- to medium-grained sandstone, and an occasional bed of black limestone, the rocks ranging from comparatively pure types to various gradations. The thickness of any single bed rarely exceeds 5 feet. As seen along the ridges, the formation appears to consist chiefly of sandstone, but that is because the soft shaly parts are covered by sandstone talus, as proved by exposures in intervening arroyos.

About 150 feet below the top of the formation is a basalt flow, 10 to 50 feet thick, characterized on the weathered surface by numerous large white laths of labradorite, An_{52}. (See pl. 7, *B*.) These are set in a dense black groundmass composed of about equal parts of chlorite and microlites of labradorite. Some residual biotite can be recognized, and one microscopic grain of augite was observed in a labradorite phenocryst. Slender needles of apatite, some skeletal, having a ratio of length to breadth of 20 to 1 are present. A foot or so of material that looks like weathered debris of the basalt locally lies at the top of this layer and merges into the overlying bed. A little above the flow layer is an equally thick layer of andesite or hornblende basalt breccia—perhaps in large part an auto-breccia—and associated with these two volcanic members are several layers of shaly and gravelly sandstone containing considerable volcanic material in the form of rock fragments and grains of feldspar. Opposite the common corner to secs. 25, 26, 35 and 36 the beds below the breccia layer are largely creamy porcellaneous shale containing a high proportion of elongate grains of feldspar whose sharp corners preclude any great amount of transportation. The distinctive flow and breccia layers and the associated tuffaceous beds seem faithfully to parallel a petrified-tree horizon (pl. 8, *C*), and these several members as a group constitute a serviceable horizon marker in a formation otherwise without a distinctive member. The two volcanic members are shown on the geologic map with a special pattern. The numerous outcrops are due to repetition by small faults and by a multitude of small folds on the warped flank of the Vista anticline. (See p. 42.) At the place where the photograph of plate 8, *C*, was taken, the flow layer is twice repeated within a distance of 100 feet. The small elliptical patches shown on the map are crusts of the breccia layer generally lying in structurally protected places, such as the hollows of the folds. The discontinuous outcrop that parallels the top contact of the formation for its full length is also the breccia layer. The other stringlike outcrops are of the flow member.

The debris that covers the hills in this area and the complex structure of the formation make it difficult to determine the detailed stratigraphic sequence or to obtain an accurate measurement of the thickness. The maximum thickness is believed not to exceed 600 or 650 feet, a figure crudely determined by adding the thicknesses, as estimated locally in the least disturbed areas, between the base of the formation and a diorite sill that parallels the base, between this sill and the volcanic section, and between the volcanic section and the top of the formation. To the south, in the area underlain by the disconformable contact, the thickness is erratic because of the irregular base, but in general it gradually lessens southward as the formation laps against increasingly higher parts of the old topography on the Broken Jug limestone. The thinning out seems due almost entirely to such overlap; there is some channeling at the top of the formation, and cobblestones and pebbles of sedimentary rock locally in the basal few feet of the overlying Hidalgo volcanics give further evidence of erosion, but the amount of material removed presumably was small, to judge from the comparatively constant interval between the top of the Ringbone shale and its breccia layer. The southward thinning out of the Ringbone by overlap evidently accounts for the absence of the formation in the Sylvanite section.

As indicated by its fossils, the Ringbone shale is a fresh-water formation, and the shallow basin of deposition presumably never covered the full area now occupied by the Little Hatchet Mountains.

FAUNA

Fossils are scarce in the Ringbone shale. The few collected were identified by Mr. Reeside. A species of *Physa* having a crenulate shoulder, a fresh-water form, was found in the isolated outcrop between the Ringbone ranch and Pothook station (fossil locality 1, pl. 12), and a few large crushed individuals of a species of *Physa* were collected from a shale bed just below the basalt member. The two collections may be from the same horizon. Fossil viviparoid gastropods were collected from a thin coquina bed at one place below the breccia member. (See fossil locality 2, pl. 12.)

HIDALGO VOLCANICS

GENERAL FEATURES

Volcanic rocks of Lower Cretaceous age are present only in the Eureka or north half of the Little Hatchet Mountains. A few generally thin layers are present in the Ringbone shale, Howells Ridge formation, and Skunk Ranch conglomerate, as mentioned in the descriptions of those formations, but the main eruptions followed deposition of the Ringbone shale. The name Hidalgo volcanics is given to this thick accumulation. It rests upon the Ringbone shale, and beyond the limits of the Ringbone shale upon the Broken Jug limestone, and is disconformably overlain by the Howells Ridge formation. The main outcrop occupies a band, ⅛ to 1½ miles broad, of rounded hills and ridges trending northwestward through the range (pl. 6, *B*), and numerous exposures crop out in the pediment of Playas Valley over a still broader area. An isolated exposure of similar volcanic rocks forms an inlier in the Howells Ridge formation at Howells Wells; it is indicated on the geologic map as probably being part of the Hidalgo volcanics but may be a layer in the Howells Ridge formation, though at a horizon somewhat lower than the known volcanic members of that formation.

The total thickness of the Hidalgo volcanics is not known, for the topmost part has been dropped from view by the Miss Pickle fault, which locally cuts out the contact between the Hidalgo volcanics and the Howells Ridge formation. The exposed thickness ranges from 900 to 5,000 feet, the wide range being due to the disconformities at the bottom and top of the formation, the effect of the two being cumulative. (See pl. 13 (1).)

The relief of the disconformity at the top amounts to at least 1,200 feet plus whatever thickness of volcanic rocks is cut out by the Miss Pickle fault. In the central part of sec. 34 a thin sedimentary member in the Hidalgo volcanics is separated from the Miss Pickle fault by 1,200 feet of lava, but in the southeast corner of the section the base of the Howells Ridge formation cuts across the lava down to this sedimentary member, lying upon it thence to the southeast as far as that member can be traced, perhaps about a mile. The absence of the sedimentary member still farther to the southeast may mean that the disconformity cuts still lower in that direction, or it may simply mean that the sedimentary member has pinched out. The disconformity at the base of the Hidalgo volcanics accounts for at least 1,400 feet of the thinning of the formation, for, as mentioned in the description of the Broken Jug limestone, that disconformity has a relief that may be well over 2,000 feet, with only the lower 65 feet or so being overlain by the Ringbone shale.

Although the thin volcanic layers of the Ringbone shale, Howells Ridge formation, and Skunk Ranch conglomerate in the Eureka area may be absent from the Sylvanite section because of nondeposition, the absence of the Hidalgo volcanics in the Sylvanite section is probably due to removal by erosion before the Howells Ridge formation was deposited. It is hard to conceive that a volcanic formation covering hundreds of square miles (see paragraphs below on age and correlation) may be over 5,000 feet thick at one place and contain hundreds of feet of pyroclastic material, yet never have been deposited at all at a point only 3 or 4 miles away. The probability is strengthened by the known great relief of the disconformity at the top of the formation.

PETROGRAPHY

The Hidalgo volcanics consist predominantly of basalt and andesite flows. Some pyroclastic material is included, and volcanic activity was interrupted at one stage long enough for a little normal sedimentary material to be deposited. The sedimentary member, which consists of thin-bedded light-gray and red limestone, red and green shale, and some gritty and conglomeratic layers, is shown on the geologic map and sections, plates 1 and 2, with a distinctive pattern. At one place the bottom of this member appears to grade into purple volcanic breccia, and its beds are accompanied by thin flow-streaked layers of brown and white felsite. The felsite layers continue to the northwest beyond the limits of the sedimentary member, and layers of volcanic breccia and of dark-purple tuff, resembling some of the mudstone and grit layers of the Howells Ridge formation, are interbedded with them. The position of the felsite and tuff layers is shown on the map by the double line of dip symbols along the continuation of the strike of the sedimentary member.

The flow rocks constitute about 90 percent of the formation. They range from greenish-gray to black and are generally dense or faintly porphyritic with feldspar or ferromagnesian phenocrysts only a millimeter or so long. Some rocks contain augite, others hornblende, and augite and hornblende basalts and augite and hornblende andesites have been recognized, but most rocks are transitional types; about two-thirds of the specimens examined would be called basalt if classified according to the composition of the plagioclase. The feldspar ranges from sodic andesine to calcic labradorite in different specimens, and some specimens contain crystals zoned within that range, the maximum zonal range observed in a single specimen being from An_{35} to An_{64}.

Layers characterized by many phenocrysts of shiny black hornblende, as much as an inch in length and constituting as much as 50 percent of the rock, are present at several horizons, particularly in the lower part of the formation. In some of the hornblende layers the accompanying feldspar is sodic andesine; in others it is sodic or calcic labradorite and the hornblende is accompanied by augite and, in one specimen, by large phenocrysts of olivine. Many of the hornblende crystals are ideally automorphic whereas others are deeply corroded by the groundmass. In thin section some are pleochroic in shades of green, others in shades of brown. Locally the hornblendic rock grades into a fine-textured diabase.

Magnetite is a common constituent of all the rocks and is extremely abundant as minute granules in the groundmass and as corrosion borders to the ferromagnesian minerals. Apatite also is common, as both stubby and needlelike crystals, and in some specimens it is pale lavender or blue and is faintly pleochroic; some grains are of phenocryst size.

The pyroclastic parts of the formation are predominantly coarse-grained breccias of the flow varieties and are similarly dark-colored. The fragmental character is not everywhere obvious, though the faint outlines of the pieces are visible on close inspection of the weathered surface. Several fine-grained tuffaceous layers contain tiny granules of basaltic rock in a matrix of calcite, chlorite, and iron ore, and other tuffaceous layers are composed of reddish and purplish andesitic material. At hill 5150 in sec. 2, just below the limestone-shale-felsite member, the formation includes 350 feet of lithified tuff containing small crystals of albite and fragments of altered rock in a partly devitrified groundmass having characteristic ash structure.

Alteration of the Hidalgo volcanics and of the other volcanic members of the Lower Cretaceous section seems everywhere far advanced. The alteration minerals consist chiefly of chlorite, calcite, and epidote; and the almost universal presence of epidote in these rocks may at some places be the only means of differentiating them from Tertiary or Quaternary volcanic rocks. A little sericite is present and is prominent in the mineralized areas, and leucoxene seems to be a common alteration product of some of the hornblende. (See pl. 8, *D.*)

Following is an analysis of the freshest rock specimen collected, an augite andesite. This rock contains about 50 percent of phenocrysts of faintly zoned andesine and 20 percent of yellowish augite, each 1½ millimeters or less in length, and several percent of large grains of magnetite, all set in an indistinct microcrystalline groundmass of feldspar and magnetite, with possibly some glass.

Analysis of augite andesite from the fault saddle of hill 5650 in sec. 33

[Contains calcite, chlorite, epidote and secondary quartz. Sp. gr., bulk, 2.802. J. G. Fairchild, analyst]

	Percent		*Percent*		*Percent*
SiO_2	**55.45**	CaO	6.83	MnO	.14
AlO_3	15.64	Na_2O	3.90	CO_2	.57
Fe_2O_3	6.96	K_2O	2.49	H_2O+	1.50
FeO	**1.72**	TiO_2	1.79		
MgO	**2.68**	P_2O_5	.62		100.29

Contact or igneous metamorphism of the volcanic rocks is described under the heading of igneous metamorphism.

AGE AND CORRELATON

The age of the Hidalgo volcanics is Glen Rose (Trinity), the same as that of the enclosing sedimentary formations.

The Lower Cretaceous volcanic rocks have been traced beyond the limits of the Little Hatchet Mountains and found to be equivalent to the earlier group of volcanic rocks of the Lordsburg mining district,[27] and I have recognized them, in the course of brief visits, in the Apache Hills on the east side of Hachita Valley, on the pediment between the Apache Hills and the Sierra Rica, and in the north end of the Florida Mountains southeast of Deming. The presence of similar volcanic rocks at several horizons in the sedimentary section in the Little Hatchets prevents, however, a more precise correlation at the moment, though the great thickness of the older volcanic rocks in the Lordsburg district and of the volcanic rocks in the Florida Mountains probably means that those rocks are the equivalent of the Hidalgo volcanics. The Lower Cretaceous volcanic rocks of the Little Hatchet Mountains may be roughly equivalent also to some thin andesitic flows in the Courtland-Gleeson region north of Bisbee, Ariz., in sediments that Wilson [28] believes resemble the Lower Cretaceous beds of other parts of Arizona, but beyond this they cannot be correlated with any other of the known pre-Tertiary volcanic rocks in the southwestern United States, for those are of Upper Cretaceous age.[29] They probably can, however, be correlated with some andesitic volcanic rocks of Comanche age that crop out in Mexico near Sahuaripa, Sonora, and perhaps also with similar rocks of uncertain age that crop out over an area of several thousand square miles in adjacent parts of Sonora and Chihuahua.[30]

HOWELLS RIDGE FORMATION

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Howells Ridge formation rests disconformably upon the Hidalgo volcanics in the Eureka part of the range but directly upon the Broken Jug limestone in the Sylvanite part, where both the Hidalgo volcanics and the Ringbone shale are missing. At both places the formation is conformably overlain by the Corbett sandstone.

In the Eureka area the formation constitutes the high cliff-capped ridge known as Howells Ridge, which is the main topographic feature of that part of the range and from which the formation takes its name. (See pl. 6, *A.*) The cliff itself is cut from massive limestone near the top of the formation, and that member tends to form a dip slope on the back side of the ridge. (See pl. 7, *C.*) The outcrop of the formation extends southeastward through the range from Playas Valley, where it forms low parallel ridges separated by valley fill, and then bends back to the northwest around the keel of the Howells Wells syncline, on the south flank of which it is cut off obliquely by the Copper Dick fault. The base of the formation is exposed only for a third or less of this outcrop length, most of its contact with the Hidalgo volcanics being along the Miss Pickle fault.

In the Sylvanite section the formation occupies a band that rises out of Hachita Valley and extends westward across the range to be largely cut off on the west slope by the Sylvanite stock. The topmost part of the formation caps the stock and extends through to Playas Valley, and a discontinuous band of metamorphosed roof pendants forms a ridge across the

[27] Lasky, S. G., Geology and ore deposits of the Lordsburg mining district, Hidalgo County, N. Mex.: U. S. Geol. Survey Bull. 885, pp. 9–14, 1938.

[28] Wilson, E. D., Geology and ore deposits of the Courtland-Gleeson region, Ariz.: Arizona Bur. Mines Geol. Ser. 5, Bull. 123, pp. 21–22, 1927.

[29] Paige, Sidney, U. S. Geol. Survey, Geol. Atlas 199, Silver City folio, pp. 7, 12, 1916. Ross, C. P., Geology and ore deposits of the Aravaipa and Stanley mining districts, Graham County, Ariz.: U. S. Geol. Survey Bull. 763, pp. 25–28, 1925. Taliaferro, N. L., An occurrence of Upper Cretaceous sediments in northern Sonora, Mexico: Jour. Geology, vol. 41, pp. 12–37, 1933. Ransome F. L., The copper deposits of Ray and Miami, Ariz.: U. S. Geol. Surv. Prof. Paper 115, pp. 56–57, 1919.

[30] King, R. E., Geologic reconnaissance of Central Sonora: Amer. Jour. Sci. 5th ser., vol. 28, pp. 81–101, 1934. King, R. E., unpublished manuscript, based on field work in western Chihuahua, Mexico, in 1933.

less-resistant intrusive rocks. Topographically the formation is characterized on the east slope of the range by parallel ridges of the hard beds extending out from the crest line, which itself follows one of the harder members for part of its course; but on the west slope toward the stock the original lithologic differences have been modified by metamorphism, and the topography consequently follows a less definite pattern.

STRATIGRAPHY

The Howells Ridge formation consists of red beds of mudstone, shale, limestone, sandstone, and conglomerate, including some coquinalike beds, overlain by massive to thin-bedded limestone, which in the Eureka section is the cliff-making member. (See pl. 7, *C*.) Thin sections of sandstone studied while the ore of the Miss Pickle tunnel was being examined disclose only sharply angular sand grains, suggesting a nearby source. Locally below the cliff-making limestone—at places directly beneath it, elsewhere as much as 150 feet below—is a layer of augite andesite flows and purple volcanic breccia ranging in thickness from 25 to 400 feet or more and grading in its thinner parts into purple shaly mudstone and arkosic volcanic grit. Where definitely recognizable as such the volcanic layer is shown with a distinctive pattern on the geologic map and sections, plates 1 and 2. The two stratigraphic sections given below illustrate the lithologic character of the formation in the type locality in the Eureka area; in the extreme western part of this area the red colors described give way to shades of gray and black, and the *Orbitolina* zone at the top becomes thinner.

In the Sylvanite section, the original distinctive lithologic features are masked by igneous metamorphism, but in general the formation resembles the type section in the Eureka area. The principal difference seems to be that the top limestone member, the *Orbitolina*-bearing beds of the Eureka section, is only 200 feet thick and unfossiliferous. In mapping, the top of the Howells Ridge formation was chosen at the upper contact of this member. In the Sylvanite area this everywhere coincides with the base of the first sandstone member of the dominantly sandstone section above, but locally in the Eureka area there is a transitional zone about 50 feet thick.

A striking feature of the formation is the rapid transition in the lower part from one kind of rock to another within very short distances laterally, as indicated in one of the measured sections below.

Section of Howells Ridge formation north of Howells Wells

[Begins at base of formation, SW. 1/4 sec. 12, T. 28 S., R. 16 W., where the dip is 30° SW., and ends in SW. 1/4 sec. 13, where the dip is 40° SW.]

		Feet
Alternating beds of shale and sandstone of the Corbett sandstone.		
Howells Ridge formation:		
Orbitolina zone:		
Limestone, thin-bedded and black; beds average about 8 inches in thickness. Includes 9 feet of brown sandstone at base. Upper few feet of limestone contains abundant *Orbitolina*	47	
Limestone, black. Beds at base 2 feet thick, grading upward to layers an inch or less thick at top. Lower thick beds contain large scattered *Tylostoma* cf. *T. mutabilis* Gabb	166	
Limestone, massive, forming the cliffs. Lower 120 feet is black limestone; overlying part is crystalline creamy-white limestone containing scattered *Toucasia* (?) and, locally, colonies of *Orbitolina*	332	
		545
Limestone, black, fossiliferous, similar to 96-foot member below. *Exogyra–Pecten* zone. (U. S. Nat. Mus. col. 17442)		17
Sandstone, coarse-grained, white, including a black fossiliferous shale member in upper part		42
Limestone, thin-bedded, black, fossiliferous. *Exogyra-Pecten zone.* (U. S. Nat. Mus. col. 16963 and 17441)		96
Shale, black, containing thin layers of limestone; members 11 to 14 feet thick and separated by subordinate beds of limestone or sandstone		162
Shale, green, limy, alternating with thin-bedded quartzitic sandstone; limy nodules 1 inch or less in diameter in the shale		70
Quartzite, medium to coarse-grained, in beds 10 inches to 2 feet thick; includes a few conglomerate beds 2 feet or less thick		74
Shale, fissile, red to green, including a few limestone and sandstone layers 1½ feet or less thick		49
Sandstone, thin-bedded, gray; beds 4 inches to 1½ feet thick, with pebbly partings and a few arkosic conglomerate layers. Includes at the base 3 feet of white limestone with argillaceous markings		21
Conglomerate		14
Sandstone, white to gray, with red shale partings		38
Shale, red, containing sandstone and conglomerate lenses		24
Miss Pickle fault, cutting out part of the formation.		
Sandstone, white, with thin red shale partings		23
Limestone, sandy, red to gray		90
Conglomerate alternating with white to red sandstone		60
Disconformity.		1,325
Hidalgo volcanics.		

The total thickness of the above section, given as 1,325 feet, does not include an unknown thickness cut out by the Miss Pickle fault.

Section of Howells Ridge formation near northwestern end of outcrop in the Eureka area

[Begins at east edge sec. 33, T. 27 S., R. 16 W., at Miss Pickle fault at first ridge west of hill 5654, and ends in S.W. ¼ sec. 32, where dip is 42° S.]

		Feet
Corbett sandstone.		
Howells Ridge formation:		
Orbitolina zone:		
Limestone, thin-bedded, black, fossiliferous. Abundant *Orbitolina*	140	
Limestone, massive, dense to crystalline creamy white. This is the cliff-making member of the formation. Scattered *Toucasia* (?)	335	
		475
Concealed. Thickness may be considerably in error because of doubtful structure		750 (?)
Limestone, gray, with argillaceous streaks and lenses in lower third and containing occasional layers of sandstone, conglomerate, and shale in overlying part. Measured thickness unreliable because of doubtful dip		635 (?)
Limestone, red, in part shaly, alternating with thick beds of conglomerate; basal conglomerate member 110 feet thick		435

Sandstone, red to white, red shale, and conglomerate, interbedded and changing abruptly and erratically from one to another within the same layers	780
Shale, red, alternating with red to creamy thin-bedded limestone; 20 feet of conglomerate at the base	167
Limestone, sandy and shaly, interbedded with subordinate sandstone and with limy and sandy shale; erratically red to green, and containing limestone members in which the argillaceous streaks and patches are red, green, or brown. Lithologically extremely variable in individual members	257
Conglomerate, bouldery, with sandstone cement in general but with shale cement here and there. Cobbles as much as 5 inches in diameter and slabs as much as a foot long and 4 inches thick; include sandstone, limestone, older conglomerate, gneiss, granite, and felsite	126
Limestone, dense, creamy-white; darker and variably shaly in top part	115
Shale, dark red to light green, containing layers of white limestone 6 inches or less thick. Discontinuous 3-foot layer of white sandstone at top	27
Partly obscured by debris, but all seems to be light-gray shaly limestone	250
	4,017 (?)

Miss Pickle fault, cutting out basal part of the formation.
Hidalgo volcanics.

The full original thickness of the Howells Ridge formation is unknown and at present indeterminable. In the Sylvanite section the present thickness amounts to 5,200 feet, including a known total of 300 feet of monzonite sills. This thickness was measured at the edge of Hachita Valley, as far as possible from the Sylvanite stock in order to minimize the effect of sill prongs from the stock and of possible deformation due to the intrusion. However, many members of the formation show considerable flow distortion (see p. 48), and consequently the original thickness must have been different from that now shown. It is not possible to evaluate this difference because the plastic flow of the beds is widespread, and the lithologic variations within the formation make it useless to compare the thickness of a less distorted part of particular bed with a more distorted part to determine the degree of compaction.

In the Eureka section the original thickness of the Howells Ridge formation is nowhere exposed, chiefly because a strike fault, the Miss Pickle fault, cuts out part of the formation. The maximum thickness measured was about 4,000 feet (see measured section above), all in the hanging wall of the fault. The disconformable base of the formation crops out in the footwall of the fault a little southeast of the line of that measured section, as shown on the geologic map (pl. 1), and the relief of the disconformity there exposed amounts to about 1,200 feet, which, added to the measured thickness, gives an approximate total of 5,200 feet. This total, however, is not reliable, even though it agrees with the thickness measured in the Sylvanite section, because the Miss Pickle fault masks the full relief of the basal disconformity and because the measured thickness is itself uncertain.

What appears on the map to be the full thickness of the Howells Ridge formation is exposed along the crest of a minor fold on the south flank of the Howells Wells syncline, but it amounts to only 1,100 feet. The difference between this and an apparent thickness of the order of 5,000 feet elsewhere is altogether in the lower part of the formation, for the limestone member at the top is of normal thickness. Distorted layers in the lower beds indicate that part of the section may have been squeezed out, but it is difficult to conceive of 4,000 feet of beds having been removed in that way. More probably, either the volcanic rock underlying the section is only a local layer within the Howells Ridge formation, such as is found elsewhere, and the full thickness of the formation is not exposed; or else the abnormal thinness, if real, is due to original deposition on a high part of the old erosion surface on the Hidalgo volcanics.

FAUNA

Fossils have been found in the Howells Ridge formation only in the Eureka part of the range. (See pl. 12.) The most prominent, and perhaps the most useful, fossil horizon is the limestone at the top of the formation, which, except in its cliff-making feature, is identical with the *Orbitolina*-bearing beds of the Broken Jug limestone. As in that formation, the *Orbitolina* are accompanied by calcitized *Toucasia* (?); and a gastropod identified as *Tylostoma* cf. *T. mutabilis* Gabb was collected at one place in the *Orbitolina* zone. Two *Exogyra-Pecten* zones are present beneath the *Orbitolina*-bearing beds north of Howells Wells at the place where one of the detailed sections given above was measured; their exact stratigraphic position, as well as that of the *Tylostoma*, is shown in the measured section. A boulder containing species of corals was picked up at the *Exogyra* locality, evidently having fallen from the cliff outcrop of the *Orbitolina*-bearing beds. A full list of the fauna is given in the table on page 16.

CORBETT SANDSTONE

DISTRIBUTION AND STRUCTURAL FEATURES

The Corbett sandstone, named from the Corbett Ranch at Granite Pass, lies conformably above the Howells Ridge formation and is overlain in turn by the Playas Peak formation along a contact that is conformable at some places but disconformable elsewhere.

In the Eureka area, the outcrop occupies a band of variable thickness lying along the flanks and keel of the Howells Wells syncline and bordering the fishhook-shaped outcrop of the underlying Howells Ridge formation. The width of the outcrop ranges from a thin edge, where the formation is sliced off by the Copper Dick fault, to a maximum of 2 miles where the beds are duplicated in the trough of the syncline. The low pass followed by the road from Howells Wells to the Skunk Ranch lies largely across the Corbett sandstone, and bordering the pass are rounded hills and bench-like ridges of the sandstone that form part of the dissected pediment described on page 8. Beyond the pediment the hills and ridges in the Corbett sandstone are similarly rounded but higher.

In the Sylvanite area the formation occupies a strip extending nearly at right angles across the range just north of Granite Pass. It is limited on the north by the underlying Howells Ridge formation and on the south partly by the Playas Peak formation and partly by the Granite Pass stock. Whereas in the Eureka area the formation forms low hills surrounded by higher ground, in the Sylvanite area it forms relatively high hills surrounded by lower ground. This difference in the Sylvanite area is due to the ready erosion of the adjacent parts of the Granite Pass stock and of the top limestone member of the underlying Howells Ridge formation, which is thin and soft there but resistant and cliff-making in the Eureka area.

STRATIGRAPHY

The Corbett sandstone consists chiefly of sandstone, in part quartzitic and massive, and variably colored black, brown, and white. Ripple marks and cross bedding are common, and some beds show a marked variation in coarseness in thin laminations. The formation contains a fair proportion of beds of sandy shale alternating with the sandstone and ranging from 1 to 15 feet in thickness, as well as several shaly and sandy limestone members in the eastern part of the Eureka area.

The contact between the Corbett sandstone and the underlying Howells Ridge formation was chosen at the sharp break between the continuous limestone section at the top of the Howells Ridge formation and the essentially continuous sandstone section of the Corbett. The upper limit of the Corbett sandstone is generally just as distinct. In the Eureka area it is a disconformable surface marked by the basal conglomerate of the overlaying Playas Peak formation. As measured from the topographic map, the thickness of the Corbett near the central part of the outcrop in that area amounts to 3,000 feet, but near the western end of the exposure the Playas Peak formation cuts down across the sandstone and the thickness is only 1,500 feet. In the Sylvanite area the basal conglomerate of the Playas Peak formation is missing, and the Playas Peak and Corbett formations are conformable, the thickness of the Corbett being 4,000 feet.

AGE AND CORRELATION

Fossils identified by J. B. Reeside, Jr., as *Trigonia* sp., *Tylostoma* sp., *Protocardia* sp., *Arctica* cf. *A. medialis* (Conrad), and *Neithea occidentalis* (Conrad) were collected at locality 33 (pl. 12) from a 1- to 2-foot bed of limestone just above the transition zone between the Howells Ridge and Corbett formations, and species of *Turritella* and *Nerinea* were collected from a 1-foot ostreid-bearing limestone bed in the section immediately overlying (locality 32). None of these forms is reported to have any critical age significance, but the age of the Corbett sandstone is nevertheless established as Trinity because of its stratigraphic position between the Howells Ridge and Playas Peak formations, both of which carry Trinity (Glen Rose) faunas.

N. H. Darton has told me that what I call the Corbett sandstone is the formation that he correlated with the Sarten sandstone in his map unit, "Sarten sandstone and underlying limestone," of Comanche age.[31] The Sarten sandstone, however, in its type locality on Sarten Ridge north of Deming,[32] contains fossils that Stanton[33] referred to the Washita group, stating that they show about the same faunal facies as are found in the marginal deposits of southern Kansas and near Tucumcari, New Mex., and that Adkins [34] compares with the Kiamichi fauna, which he places in uppermost Fredericksburg.

PLAYAS PEAK FORMATION

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Playas Peak formation is named from a high peak in the Eureka area at whose foot the formation is exposed. In that part of the range the formation occupies a V-shaped outcrop lying disconformably above the Corbett sandstone and cupped within the trough of the Howells Wells syncline. One arm of the V, along the north flank of the syncline, is cut off by the wash of Playas Valley and the other by the Copper Dick fault, which brings the Playas Peak formation at and south of Livermore Spring into contact with the intrusive rocks and metamorphosed sediments of the Sylvanite area. The formation is overlain disconformably by the Skunk Ranch conglomerate, but at Playas Peak the contact and adjacent parts of both formations are covered by Tertiary volcanic rocks, from which they are separated by an angular unconformity.

The upper part of the Playas Peak formation in the Eureka area, for about one-third the length of the outcrop, is marked by a ridge of limestone curving around the axis of the Howells Wells syncline, and a thick basal conglomerate tends to form a parallel ridge, but in general the formation occupies part of a dissected pediment that flanks the sharp cliffs of the Tertiary volcanic rocks. (See p. 8.)

In the Sylvanite area the Playas Peak formation crops out only at the two ends of Granite Pass, the intervening part being cut out by the Granite Pass stock. The eastern exposure is a small triangular patch of soft marmorized limestone lying between the granite and the Corbett sandstone at the very beginning of the pass and forming part of the pediment there. The western exposure forms a group of low ridges flanking the Corbett sandstone. Several isolated patches, in part limited by tongues of wash from Playas Valley and in part by croppings of the stock, are included in this exposure.

STRATIGRAPHY

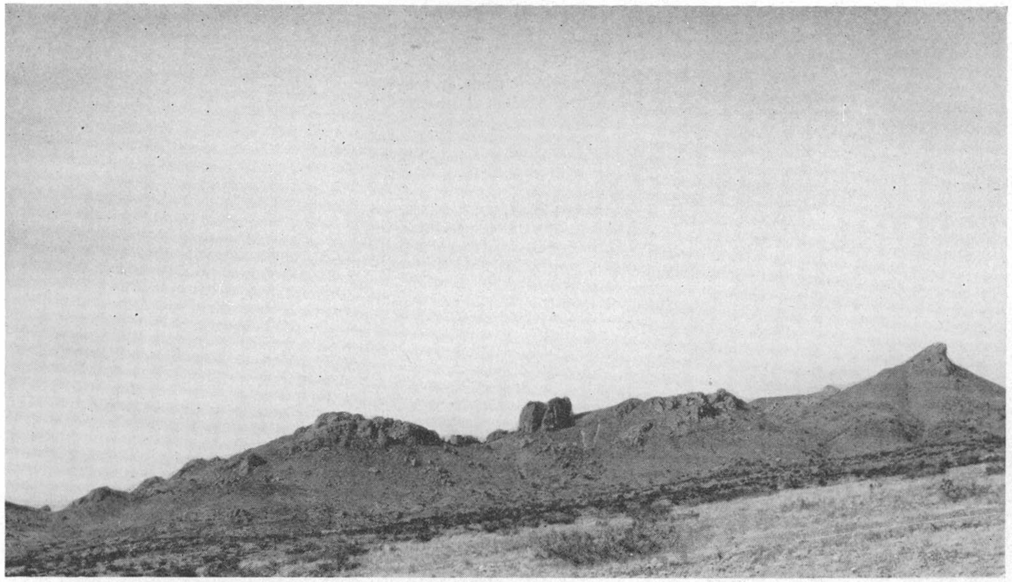
The Playas Peak formation consists of sandstone and shale underlain in the Eureka section by a basal conglomerate and capped by massive fossiliferous limestone. At the axis of the Howells Wells syncline, the basal conglomerate is a bouldery unsorted mass that resembles the conglomerate of the Broken Jug limestone east of the Ringbone ranch and the basal conglomerate of the Ringbone shale. The following section was measured at that place:

[31] Darton, N. H., U. S. Geol. Survey Geologic map of New Mexico, 1928.

[32] Darton, N. H., Geology and underground water of Luna County, N. Mex.: U. S. Geol. Survey Bull. 618, pp. 43–44, 1916.

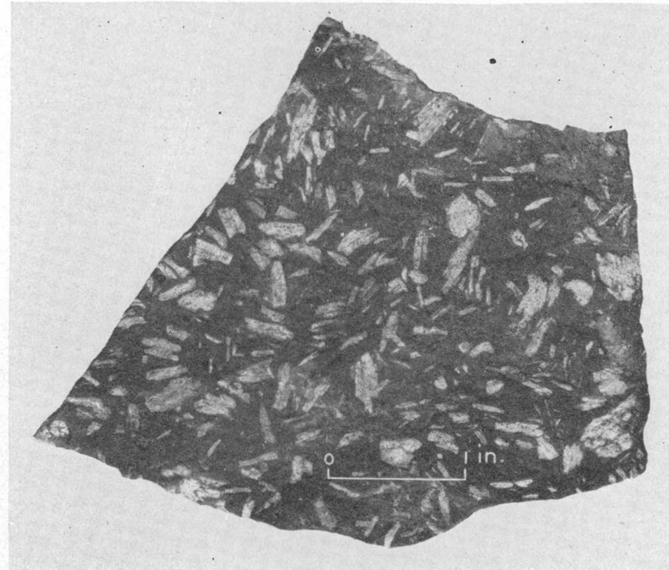
[33] Idem.

[34] Sellards, E. H., Adkins, W. S., and Plummer, F. B., The geology of Texas: Univ. of Texas Bull. 3232, vol. 1, p. 281, 1932.



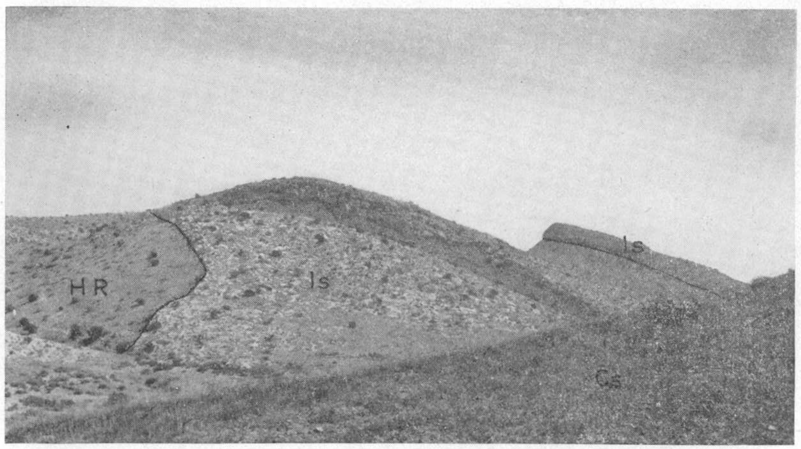
A MIOCENE (?) BRECCIA AND TUFF WEST OF LIVERMORE SPRING.

View westward.



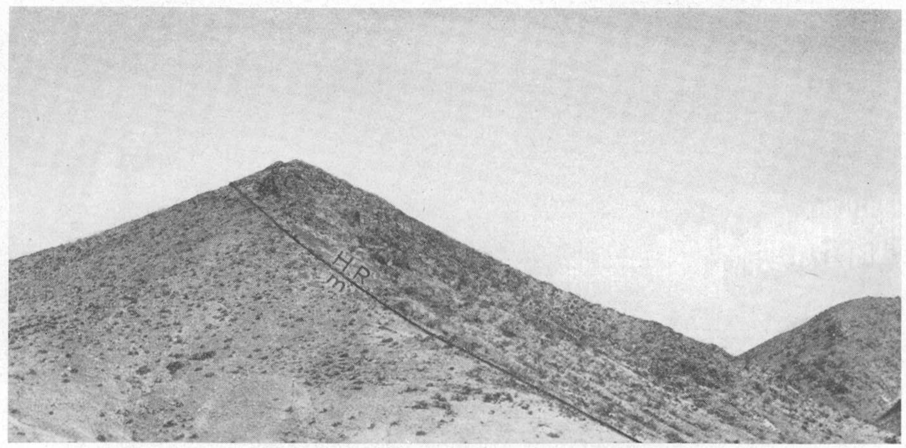
B. WEATHERED SPECIMEN OF THE BASALT LAYER OF THE RINGBONE SHALE.

Shows the characteristic appearance of the rock.



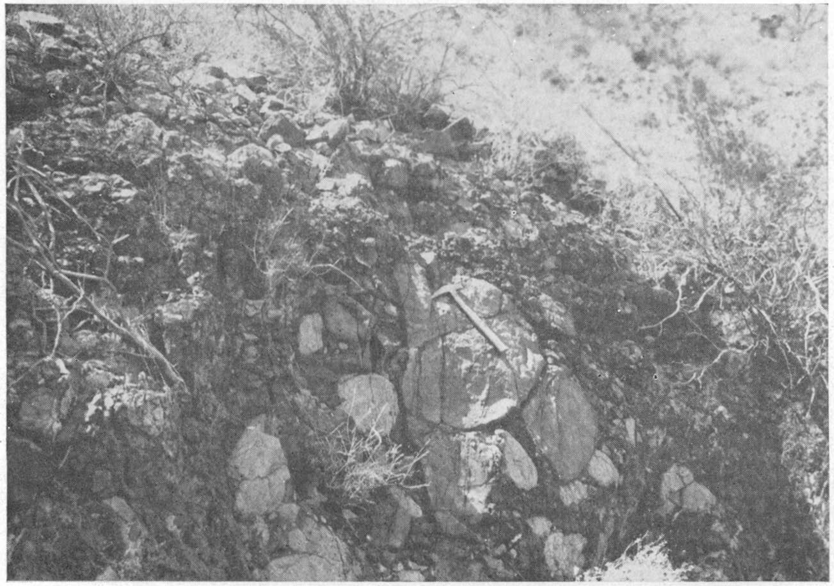
C. HOWELLS RIDGE FORMATION ON BACK SLOPE OF HOWELLS RIDGE.

Lower beds of Howells Ridge formation (HR) where cliff-making limestone member (ls) at top of formation has been eroded. Slope in right foreground is on Corbett sandstone (Cs). View eastward from saddle near end of old stage road in sec 11.



D. CONFORMABLE CONTACT BETWEEN MONZONITE OF THE SYLVANITE STOCK (m) AND METAMORPHOSED BEDS OF THE HOWELLS RIDGE FORMATION (HR).

View nearly due east from Sylvanite. Draw at right leads to the Green (Little Mildred) mine.



A. UNSORTED BOULDERY CONGLOMERATE OF THE BROKEN JUG LIMESTONE.

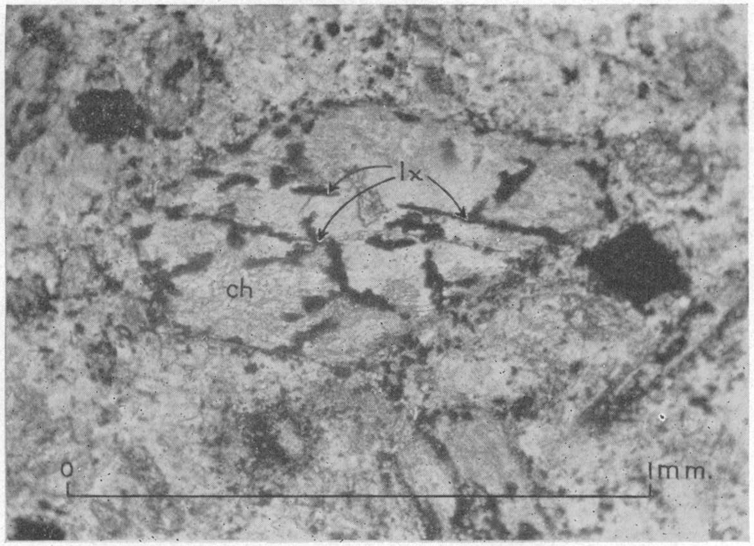
East side of beacon hill near the Ringbone ranch.

B. BASAL CONGLOMERATE OF THE RINGBONE SHALE.

Just south of the common corner of secs. 25, 26, 35, and 36, T. 27 S., R. 16 W

C. SMALL ANTICLINE IN THE RINGBONE SHALE.

SE. ¼ sec. 22, T. 27 S., R. 16 W. Camera case is lying on a petrified log. The basalt flow that parallels the fossil wood horizon crops out in a similar fold on the opposite bank of the arroyo.



D. PHOTOMICROGRAPH OF ALTERED SPECIMEN OF THE HIDALGO VOLCANICS.

Shows chlorite pseudomorph of hornblende (ch) with the original cleavage outlined by grains of leucoxene (lx). Plain transmitted light.

Composite section of Playas Peak formation near axis of Howells Wells syncline

[Lower part, up to *Orbitolina* zone, measured by R. F. Pettit on south flank of syncline, just north of Grand-Hidalgo county line; *Orbitolina* zone measured on north flank along draw showing dip 70° SW.]

Bouldery red conglomerate of the Skunk Ranch conglomerate.	
Disconformity.	
Playas Peak formation:	
Orbitolina zone:	*Feet*
Limestone, massive, gray; scattered *Toucasia*	37
Partly concealed but seemingly soft yellow sandstone containing several limestone layers 1 to 2 feet thick	126
Limestone, thin-bedded, blue; scattered *Toucasia*	29
Limestone, massive, blue to brown; *Toucasia* and *Orbitolina* at bottom	11
Limestone, thin-bedded, in layers 1 foot thick, *Toucasia* and *Orbitolina*	11
Limestone, thick-bedded; *Orbitolina* horizon	56
Limestone, thin-bedded, dark, bedding planes 3 inches apart	14
Limestone, thick-bedded; scattered small *Toucasia*	20
Limestone, dark, very thin-bedded	20
Limestone, blue, in beds about 2 feet thick	35
Limestone, massive, blue; abundant *Orbitolina*	5
Limestone, blue, in beds 4 feet thick	14
Limestone, massive, blue; scattered *Orbitolina*	9
	387
Bedding plane (?) fault.	
Sandstone, brown. Upper part largely concealed	88
Limestone, grayish-blue	6
Sandstone, brown to white	46
Latite sill	44
Largely concealed by alluvium, through which appear isolated outcrops of sandstone, shale, and limestone. A short distance west, 25 feet of alternating red sandstone and shale crops out in this part of the formation	331
Concealed	40
Latite sill	44
Sandstone, brown to white	160
Shale, green	8
Limestone, blue, locally grading toward limestone conglomerate	16
Quartzite and sandstone, white to pink and green	52
Conglomerate, containing boulders of limestone, coquina, sandstone, and conglomerate as much as 2½ feet in diameter. Only Lower Cretaceous rocks recognized among the boulders	140
	1,335
Disconformity.	
Alternating sandstone and shale of the Corbett sandstone.	

The thickness of the above section, exclusive of sills, is 1,274 feet.

To the west the basal conglomerate thins down to a 30-foot bed of coarse-grained angular arkose containing a few rounded pebbles of limestone; still farther west this bed contains more and more sand, and eventually, at a point southeast of the Skunk Ranch near the blanket of high alluvium, becomes indistinguishable from the enclosing beds. The exact position there of the base of the formation consequently is uncertain, but the basal conglomerate again crops out in the far western part of the exposure along the north foot of Playas Peak, where it is 135 feet thick and includes a few sandstone members having thin shale partings. The beds above the conglomerate in that area are too poorly exposed to permit any detailed measurement, but they appear to consist chiefly of green and brown shales with 10 or 15 percent of light-colored and hard sandstone and grit in beds 2 inches to 2 feet thick. Some thin layers of limy mudstone and layers of white clay shale were recognized. The median part of this section is composed of 75 feet of more massive sandstone containing a few shale members a foot or so thick.

The 400 feet or so of fossiliferous limestone that caps the formation at and south of the syncline axis is cut out a short distance west of the measured section by the disconformably overlying Skunk Ranch conglomerate. What is evidently the same limestone member likewise forms the uppermost part of the formation at Granite Pass.

The thickness of the Playas Peak formation in the Eureka area appears to range between 800 and 2,000 feet, the variation being due to the disconformities that limit it at both top and bottom. At Granite Pass the exposed thickness is fully 3,000 feet, with the top of the formation cut out by the granite or covered by alluvium.

FAUNA

The limestone at the top of the Playas Peak formation contains crowded colonies of *Orbitolina*, as indicated in the measured section given above, and numerous calcitized individuals of *Toucasia*. In one collection the *Toucasia* was identified as *T. texana* (Roemer)? Large gastropods several inches in diameter and identified by Reeside as *Amauropsis* (?) cf. A. *pecosensis* Adkins were collected from an apparently isolated but crowded colony in one of the massive beds of the *Orbitolina* section. (See p. 14.)

Fresh-water forms, including *Unio* sp., *Planorbis* sp., *Physa* sp., and *Viviparus* sp., were collected from limy nodules in one of the shale beds below Playas Peak (locality 18), and some similar forms were collected from a sandy shale about 50 feet stratigraphically below the *Orbitolina* zone (locality 40). Fragments of petrified wood have been observed in the shale-sandstone part of the formation.

SKUNK RANCH CONGLOMERATE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Skunk Ranch conglomerate lies disconformably upon the Playas Peak formation and occupies an irregular strip near the west edge of the range and west and south of the Skunk Ranch, from which the formation is named. The outcrop is much dissected by tongues of alluvium from Playas Valley, and much of the formation is covered by Tertiary volcanic rocks, which mark the upper limit of the exposure. Like the underlying formations, the Skunk Ranch conglomerate is cut off on the south by the Copper Dick fault, which has dropped it against the Sylvanite monzonite.

In the broader parts of the outcrop, erosion has carved the formation into parallel ridges and drains that follow the trend of the beds and that now constitute the remnants of an old pediment (see p. 8), but elsewhere the Skunk ranch conglomerate forms the smoother and moderately steep slopes that foot the cliffs of the overlying Tertiary rocks.

STRATIGRAPHY

The Skunk Ranch conglomerate consists largely of red conglomerate containing red boulders and pebbles in a matrix of red sandstone and shale. The average diameter seems to be about 4 inches, but some boulders and slabs are fully 20 inches across. Lateral gradations from the bouldery red conglomerate to finer-grained and normal-colored limestone conglomerate and to coarse-grained sandstone are exposed here and there. The stratigraphic section given below was measured west of the Skunk Ranch, where the exposures are most continuous. In the lower half of the section the boulders and pebbles of the conglomerate include older conglomerate, fossiliferous limestones, sandstone, petrified wood, and basalt, all rocks that could have been derived from the beds of Trinity age below. In the upper half, on the contrary, in the 1,300 feet or more of alternating red shale and red conglomerate, many of the limestone boulders contain Paleozoic fossils, apparently Pennsylvanian and Permian (?), and the accompanying sandstone boulders seem invariably red, as though, with the red shale, they had been derived from Permian redbeds; no pebbles that could be referred with confidence to the Lower Cretaceous rocks were identified in this part of the section.

Section of the Skunk Ranch conglomerate across north half of secs. 7 and 8, T. 27 S., R. 16 W., west of the Skunk Ranch

	Feet
Tertiary volcanic rocks.	
Angular unconformity.	
Skunk Ranch conglomerate:	
Largely covered by debris, through which crop out small exposures of gray conglomerate, sandstone, and gray to maroon shales	200
Concealed	335
Alternating massive red conglomerate and red clay shale, shale predominating	535
Grayish-red sandstone in layers 4" to 1' thick	67
Alternating massive red conglomerate and red clay shale in members 5 to 60 feet thick	760
Massive light-green sandstone, generally soft but containing several hard and gritty cross-bedded layers	130
Concealed	35
Fine-grained yellow and brown sandstone and grit in layers 2 inches to 1 foot thick	85
Concealed	170
In part concealed but largely fine-grained to coarse, bouldery conglomerate	360
Yellow clay shale	8
Concealed	53
Fine-grained yellow sandstone	4
Conglomerate with sandstone lenses	49
Alternate beds of conglomeratic sandstone and clay shale	42
Interbedded yellow clay shale and gritty sandstone	40
Gray sandstone containing numerous conglomeratic lenses	12
Soft greenish shale with several thin layers of sandstone	22
Concealed	124
Sandy conglomerate	12
Yellow clay shale	6
Yellow soft nodular sandstone	6
Conglomerate like that below	8
Concealed	207
Massive conglomerate containing pebbles and boulders ranging from less than 1 inch to over 20 inches in diameter; average diameter is 4 or 5 inches	78
	3,348
Gritty sandstone of the Playas Peak formation	28
Latite sill.	

South of the arroyo leading west from the Skunk Ranch, the formation is almost completely covered by Tertiary volcanic rocks, but it crops out again in the area west of Livermore Spring, where it contains a 200-foot layer of augite basalt. (See geologic map and sections, pls. 1 and 2.)

Inasmuch as the top part is hidden by the Tertiary rocks, the original total thickness of the Skunk Ranch conglomerate cannot be determined. The thickest parts exposed are in the section west of the Skunk Ranch, as given in detail above.

AGE

No fossils have been found in the Skunk Ranch conglomerate other than some algae in a limestone bed directly above the volcanic member, and consequently the age of the formation cannot be known with certainty.

Inasmuch as the geologic history of the formation, however, as indicated by the lithologic features, the disconformable base, and the intercalated volcanic member, fits so well into the general history of deposition of the underlying rocks, the Skunk Ranch conglomerate is assumed to belong to the same epoch and therefore to be of Trinity age.

QUARTZITE AND LIMESTONE OF UNCERTAIN AGE

Patches of sedimentary rock, consisting of white quartzite overlain by thin-bedded very sandy limestone, form the western slopes of the isolated granite hills at Hatchet Gap. The maximum thickness exposed is about 275 feet.

No fossils could be found. The formation occupies the same relative position with respect to the Playas Peak formation as does the Skunk Ranch conglomerate, but it is separated from the Playas Peak formation at Granite Pass by 3 miles of granite intrusive into both formations.

ORTHOCLASE GABBRO OF LOWER CRETACEOUS (?) AGE

An unusual rock, classified as an orthoclase gabbro, crops out at the edge of the alluvium in secs. 25 and 30 at the northeast corner of the range, where it intrudes the lower beds of the Broken Jug limestone as a crosscutting mass with sill-like tongues. There seems to be no contact metamorphism of the inclosing rocks.

The gabbro is a dark-gray, variably textured rock weathering brown to black and breaking down into bouldery shapes. The main mass is a medium-grained porphyritic rock marked by plates of gray calcic andesine (An_{46}) as much as a centimeter long; these are set in a diabasic-textured groundmass of thin well-developed plates, 0.4 to 3 millimeters in length, of calcic labradorite (An_{64}) and interstitial and poikilitic pink orthoclase. The orthoclase constitutes about a fourth of the rock. Included in the interstitial material are irregular patches and shreds of brown biotite, in part chloritized and originally composing perhaps as much as 15 percent of the rock. The accessory minerals include abundant magnetite, a few needles of ilmenite, and abundant corroded grains of apatite, some of them skeletal. This rock is cut by dikelets of pink aplite, 3 inches or less thick, consisting of euhedral grains of microcline and orthoclase and a little interstitial quartz.

To the west are two small croppings of a fine-grained nonporphyritic facies of the gabbro cut by thin threads of a pink rock that differs from the rest only in having a preponderance of pink orthoclase and in the absence of dark minerals. Mineralogically the pink threads are transitional between the main rock and the aplite dikelets and presumably represent residual liquid rich in orthoclase squeezed into cracks in rock already formed. Skeletal needles of apatite having a ratio of length to breadth of as much as 20 to 1 are prominent in this fine-grained phase. To the south is a thin, sill-like finger of the gabbro consisting of about 70 percent of calcic labradorite in diabasic arrangement with altered colorless augite. About 10 percent of orthoclase, locally intergrown with a trace of quartz, is interstitial to the plagioclase. A little uralite, secondary to the augite, and a few shreds of biotite are present. The accessory minerals, as in the other specimens, include abundant magnetite, a little ilmenite, and delicate skeletal needles of apatite.

The best general name for this rock seems to be orthoclase gabbro. The coarse-grained porphyritic facies may be called biotite-orthoclase gabbro whereas the rock of the sill-forming facies may be classed as granophyric gabbro, a name given to a gabbro containing an interstitial intergrowth of quartz and orthoclase.

The age of the gabbro and its igneous affiliations are uncertain. The rock is cut by lamprophyre dikes and therefore, so far as its relation to other rocks is concerned, either may belong to the late Cretaceous or early Tertiary period of intrusion or may be the plutonic equivalent of the Lower Cretaceous volcanic rocks. The gabbro has been found only in the Broken Jug limestone, which is older than the volcanic rocks, and this fact, even though merely negative evidence, fits the second possibility. Furthermore, the mineralogic similarity between the gabbro and the basalt flow in the Ringbone shale (p. 19) suggests that the two rocks may be closely related; for if the porphyritic facies of the gabbro had been quickly chilled, it would have yielded a rock similar to the flow, even to the slender needles of apatite. The presence of orthoclase and aplite in the gabbro would seem to have no critical significance, because the separation of orthoclase from a gabbroid magma, though not common, is quite possible.[35] For these reasons the gabbro is classed as of Lower Cretaceous (?) age, but with no stronger evidence than here cited.

On the other hand, it is conceivable, as suggested by the aplite dikelets and the orthoclase-rich threads, that the small exposed mass of gabbro may be only a border facies of a more potassic mass below and consequently related to the late Cretaceous or early Tertiary rocks. If that should be true, the gabbro presumably would be related to the diorite sills, for the absence of contact metamorphism is opposed to its belonging to the main stage.

It will be noted on plate 4 that the gabbro is intermediate between the Lower Cretaceous lavas and the diorite and could be related to either insofar as that position in the igneous sequence is concerned. But this reference to the chart calls attention to still another possible affiliation, because the gabbro could be placed just as well between the aplite and lamprophyre dikes and still be in accord with field relations. The mineral composition and fabric of the rock are suggestive of some of the lamprophyre dikes, and the association with orthoclase-rich threads and apalite dikelets would conform with the theory that lamprophyres and aplites are complementary rocks.

[35] Bowen, N. L., The evolution of igneous rocks, pp. 98–102, 228–233, Princeton Univ. Press. 1928.

LATE CRETACEOUS OR EARLY TERTIARY ROCKS

DIORITE SILLS

The earliest of the late Cretaceous or early Tertiary rocks is a group of diorite sills intrusive into the Broken Jug, Ringbone, and Howells Ridge formations in the Eureka area and folded with them. Several thin sills are enclosed in the Playas Peak formation, but they are believed to be related to some later latite dikes rather than to the diorite. (See p. 35.)

In general the diorite croppings are discontinuous and podlike. They tend to lie near the base of the massive limestone member at the top of the Broken Jug limestone, at and just above the base of the Ringbone shale, and near the base of the limestone member at the top of the Howells Ridge formation. They are most abundant in the Broken Jug limestone near Old Hachita. In the southeast corner of sec. 34, T. 27 S., R. 16 W., a roughly circular outcrop about 600 feet in diameter lies at the base of the Howells Ridge formation, with tapering sill fingers extending out along the contact and along the sedimentary member of the underlying Hidalgo volcanics. The thickness of the diorite sills ranges from a few feet to 275 feet or more; the thickest are some of those at Old Hachita and the one in the Ringbone shale near the Ringbone ranch.

The rock of the sills is medium gray to greenish-gray, weathering dull pink, and is porphyritic with phenocrysts of gray feldspar averaging 1 or 2 millimeters in length in a groundmass whose average grain size is less than a tenth as large. The phenocrysts constitute 30 to 40 percent of the rock and include andesine, or zoned crystals of andesine-labradorite having a rare outer zone of oligoclase, a little orthoclase, altered hornblende, and, more rarely, flakes of altered biotite and grains of quartz. Numerous minute grains of magnetite can be seen in some hand specimens. The groundmass consists of interlocking grains of quartz and feldspar, in part striated, in a mesh of chlorite. Accessory minerals are rare zircon and generally abundant apatite, which forms small slender needles and stubby corroded grains as much as 0.7 millimeter in length.

The diorite is everywhere somewhat altered, particularly its hornblende and biotite, which as a rule are completely changed to chlorite, or to chlorite and calcite, with scattered grains of leucoxene. A little epidote is everywhere present. The following analysis shows the chemical nature of the rock.

Analysis of diorite from outcrop in sec. 26, T. 27 S., R. 16 W.

[Contains chlorite, calcite, sericite, epidote, and leucoxene. Sp. gr., 2.743. J. G. Fairchild, analyst]

	Percent		Percent		Percent
SiO_2	55.33	CaO	5.20	CO_2	1.73
Al_2O_3	16.46	Na_2O	4.62	P_2O_5	.59
Fe_2O_3	3.43	K_2O	2.93	MnO	.09
FeO	3.70	H_2O	2.24		
MgO	2.55	TiO_2	1.34		100.21

Injection of the sills antedated formation of the ore deposits; no immediate genetic connection seems to exist between the two, and the diorite caused no igneous metamorphism.

MONZONITE AT OLD HACHITA

Several bodies of light-colored fine-grained rock intrude the Broken Jug, Ringbone, and Hidalgo formations at and west of Old Hachita in the Eureka area. They include monzonite and a syenitic rock that differs petrographically from the monzonite only in containing a more sodic plagioclase. The type of alteration, general appearance, and degree of associated contact metamorphism of the two facies are generally distinct in the field, and they justify the separation of the rock into two map units, despite a few confusing resemblances that may have led to incorrect assignment of one or two of the smaller outcrops.

The outcrops of the monzonite are so small and in general of such color tone as to be inconspicuous among the light-colored rocks of the metamorphic halo that surrounds them. The main exposure is on the low hill at Old Hachita on which the Maine claim is located. (See pls. 5 and 20.) Another patch crops out just to the south, on the American claim and across a wash-filled draw, and a third crops out still farther south on the south side of a second draw. These three outcrops are probably continuous beneath the wash, and together they form a mass about 3,000 feet long and 500 feet thick that lies sill-like within the metamorphosed Broken Jug limestone above the main *Exogyra*-bearing coquina member. The southernmost tip of this mass is limited by the Ohio fault, though the metamorphic halo continues; and on the north both the monzonite and the metamorphic rocks are cut off by the National fault zone, which brings them against the unmetamorphosed equivalents of the same beds and against the diorite sills. A little garnetized rock crops out on the ridge of the Howard vein about 1,000 feet still farther north (see pl. 1), and the monzonite may be continuous below the surface in that direction. A second sill-like mass, 1,200 feet long and 200 feet thick, lies a little below the *Exogyra*-bearing member.

The outcropping parts of the monzonite generally consist of a light-gray to nearly white, fine-grained, porphyritic rock, weathering white or tan. The rock contains 30 percent or less of phenocrysts of orthoclase and sodic andesine, 1 to 2 millimeters in length, in a groundmass of andesine and orthoclase whose grains average about 0.2 millimeter in diameter. Some zoned phenocrysts (An_{32-43}) were seen. Alteration obscures the relative proportions of orthoclase and plagioclase, but these minerals seem to be about equally abundant. One specimen contains numerous small grains and a few imperfect phenocrysts of augite, and another contains small grains of a pale hornblende and clusters of this pale hornblende that are pseudomorphic after some other ferromagnesian mineral. Sphene and apatite are exceptionally abundant in thin sections, though the chemical analysis made does not indicate an abnormal content of TiO_2 or P_2O_5. The rock is everywhere sprinkled with pyrite or spots of limonite, and other alteration minerals include epidote, sericite, chlorite, calcite, and manganosiderite. The following analysis illustrates the chemical nature of the rock.

Analysis of monzonite from the Maine claim, Eureka district, Little Hatchet Mountains, N. Mex.

[Contains epidote, sericite, calcite, chlorite, secondary sphene, and secondary (?) hornblende. E. T. Erickson, analyst]

	Percent		Percent		Percent
SiO_2	58.64	CaO	3.18	CO_2	Present
Al_2O_3	19.07	Na_2O	5.95	P_2O_5	0.18
Fe_2O_3	3.19	K_2O	3.74	MnO	.005
FeO	1.87	H_2O	.96		
MgO	1.85	TiO_2	.58		99.215

SODIC FACIES OF THE MONZONITE

The sodic facies of the monzonite is intrusive largely into the Hidalgo volcanics. A patch of it crosses into the Ringbone shale at Old Hachita and smaller patches lie within the Broken Jug limestone on the Copper King claim. As with the monzonite, these masses are sill-like in form—the small outcrops in the Broken Jug limestone are ideally parallel to the bedding; the body at Old Hachita follows the contact between the Ringbone shale and the Hidalgo volcanics; and the main body, 1¾ miles long and ½ mile wide, parallels the general northwestward trend of the sedimentary structure.

In contrast to the strong metamorphic halo around the monzonite, the only contact-metamorphic alteration associated with the sodic facies seems to be a faint uralitization of the mafic minerals in the Hidalgo volcanics at the contact. (See p. 56.) Perhaps a little specularite in the Ringbone shale at Old Hachita and the silicated rocks farther east on the ridge may be attributed to the sodic rock, but also they may be related to the monzonite, and furthermore the specularite may have a later hydrothermal origin, for such specularite is present nearby. Some of the widespread epidote in the Hidalgo volcanics may have been produced by emanations from the sodic facies, but there is no concentration of epidote near the sodic facies comparable to that in the metamorphic halo of the monzonite.

The fresher parts of the sodic rock are light gray or creamy white, like the monzonite, though the sodic facies is the finer-grained, the average diameter of the grains in the groundmass being considerably less than 0.1 millimeter. Over most of the outcrop the sodic facies is altered to a pink, red, brown, or yellow iron-stained rock or is bleached to a chalk white and speckled with pockets of jarosite. This alteration is the result of oxidation of considerable pyrite, which is abundant in the fresher rock and is represented by many "limonite" casts in the altered rock. The effect of alteration extends well into the surrounding basalt at some places, and the contact would be difficult to find were it not for the abundance of epidote in the altered basalt and its apparent absence from the intrusive. The preserved structure of the basalt breccia was found serviceable in differentiating the two rocks, but it is not an infallible indicator because at one place, at least, the intrusive rock has an auto-breccia border that resembles the volcanic breccia. A chilled border phase is present locally.

One of the freshest specimens collected is from one of the small outcrops at the Copper King mine. This rock is outwardly almost identical with the nearly white parts of the nearby monzonite, but it contains albite instead of andesine. A light-gray to pink rock similar in appearance to parts of the monzonite crops out in sec. 1 to the southwest and near the edge of the metamorphic halo in the basalt, and it also contains albite—as sodic as An_2—instead of andesine. In other specimens, all from the main mass, the phenocrysts are so altered and the groundmass so fine-grained that difficulty was encountered in determining the composition of the plagioclase. In some specimens both andesine (about An_{40}) and oligoclase (about An_{15}) were recognized. In others, too much altered for precise determinations, the plagioclase includes some grains having all indices greater than that of Canada balsam and other grains having some indices less than that of balsam; and in one such specimen a phenocryst, properly oriented and sufficiently fresh for identification, consisted of andesine (An_{39}) partly replaced by oligoclase (An_{14}). Like the monzonite, the sodic rock has residual augite or secondary hornblende and is exceptionally rich in sphene and apatite.

Presumably the albite in the two specimens described above and the oligoclase in the others are the results of the same or related processes of sodic alteration of the original monzonite, and therefore the presence of oligoclase poses a problem as to the environment in which that alteration took place, for ordinarily hydrothermal plagioclase is sodic albite. It appears that the alteration started at a late pyrogenetic stage (see p. 32), and consequently I have used the general term "sodic facies of the monzonite" to describe this rock instead of some more specific term.

MONZONITE PORPHYRY DIKES OF THE EUREKA AREA

A large number of monzonite porphyry dikes, only some of which are shown on the geologic map, cut all other rocks, except some lamprophyre and later felsite and latite dikes, in the country north of the Miss Pickle fault in the Eureka area. Croppings have been seen as far north as the pediment northeast of Pothook station. They are of particular interest because most of the veins around Old Hachita are associated with them. In that vicinity they are so much more susceptible to erosion than most of the beds of the Broken Jug limestone that they weather below the level of the sediments, and, where closely spaced, as on the ridge of the King vein, give a false impression of bedding.

The dikes range from thin stringers only a foot or so thick to bodies as much as half a mile or more long and 100 feet thick. Plate 22 shows the intricate outline assumed by many. In color they range from pink through various shades of gray to nearly black, the border facies and prongs of some dikes being darker than the main parts. Their most characteristic feature is the presence of phenocrysts of apatite, generally 2 or 3 millimeters in length and having a ratio of length to breadth of 3 or 4 to 1, and of isolated thin, pseudohexagonal books of shiny brownish-black biotite, whose thickness seems to average about a third the diameter. These two minerals serve to distinguish the monzonite porphyry dikes from the other igneous rocks of the area, particularly from diorite sills in mine workings, for regardless of alteration the apatite phenocrysts and the structure of the biotite books are still megascopically recognizable.

A very few of the dikes have hornblende instead of biotite; others have both these minerals. The feldspars include albite—or, in one specimen, oligoclase-andesine—and orthoclase, the orthoclase being confined largely to the groundmass. The composition of the albite ranges, in the several specimens examined, from An_3 to An_8. Rare phenocrysts of quartz are present, but in general quartz is scanty. The accessory minerals include sphene, zircon, and magnetite.

THE SYLVANITE COMPOSITE STOCK

The intrusive body at Sylvanite is a composite stock of monzonite and later quartz monzonite that occupies a subrectangular area of about 6 square miles on the west flank of the range. It displaces a part of the Broken Jug limestone and more than three-fifths of the thickness of the Howells Ridge formation, and the metamorphosed silicated beds of those formations border the intrusion on the northeast and southeast, respectively. To the southwest the stock in part is bordered by the silicated beds of the Howells Ridge formation and in part passes under the wash of Playas Valley; if the attitude of the stock with respect to the enclosing beds is the same in the wash-covered area as elsewhere, its southwestern limit under the valley fill probably lies along the line connecting the exposed parts of the contact. To the northwest the stock is sharply cut off by the Copper Dick fault, which brings it against the unmetamorphosed sediments of the Corbett, Playas Peak, and Skunk Ranch formations of the Eureka area.

The monzonite and quartz monzonite that constitute the stock are commonly more susceptible to erosion than the other rocks, and they tend to occupy a basin rimmed by the other rocks and sloping westward to Playas Valley. Sylvanite lies near the center of the basin at a gap in a westward-trending ridge formed by a tongue of hard silicated rocks of the Howells Ridge formation. Next to the valley, the monzonite has been largely planed off to very gentle slopes, which merge smoothly into the surface of the valley fill.

In general attitude the mass parallels the strike and dip of the enclosing sedimentary formations but has a blunt and almost square-cornered southeastern end, which, however, is made up of three or four principal sill-fingers that end at about a common line. (See pl. 1.) Countless thinner sills and dikelike apophyses extend out into the enclosing rocks; a few of these are of sufficient size to be shown on the geologic map, but most are only a few feet thick. (See pl. 25.) The southwestern boundary of the mass is concordant with the Howells Ridge formation, and the northeastern boundary is fairly concordant with the Broken Jug limestone, crosscutting contacts being local only. The northward bulge on the slope of Hachita Peak, as seen in plan, plate 1, is no more than a skin of monzonite forming, as it were, a dip slope. (See pl. 2, sec. Q-Q'.) The Howells Ridge formation thus constitutes the roof of the intrusive body and the Broken Jug limestone the floor, the thickness from floor to roof normal to the bedding being close to 7,000 feet. An almost continuous tongue of the Howells Ridge formation, split longitudinally by thin sills of monzonite, extends westward across the stock with generally concordant contacts (see pls. 6, *C*, and 7 *D*), and a similar but less continuous tongue of Broken Jug strata penetrates the northern part of the mass, relations suggesting that the mass in its upward course has split into three main sill-like members, as shown on plate 13. The original extent of the three members is discussed in the section on structure, and the conclusion is there offered that the Sylvanite stock was originally continuous with the stock at Old Hachita as a mass that extended, like a gigantic horseshoe nail, for 7 miles or more at and near the top of the Broken Jug limestone. It is further postulated that both this nail-like injection and the Granite Pass composite stock are long streamers from the top of a deeper discordant body.

MONZONITE

The monzonite constitutes well over nine-tenths of the exposed part of the stock. It ranges from a grayish-pink medium-grained and apparently granitoid rock to much darker, finer-grained, denser facies. (See table.) Though most of the rock seems to consist of different-textured varieties of the light-colored facies, in a general way the monzonite seems to be light-colored where intrusive into the Broken Jug limestone and darker in the Howells Ridge formation. The lighter facies tends to weather a mottled white but is decidedly green where strongly epidotized, as is common. At many places, and most generally in the border zones, the rock is fine-grained and nearly white and closely resembles the monzonite at Old Hachita and its sodic facies.

Microscopic study and chemical analyses show all facies to be much alike, though the dark facies seems to be a little the more dioritic. (See analyses.) The average rock has a characteristic monzonitic texture and contains an estimated 30 or 35 percent of orthoclase and microcline, 40 or 45 percent of plagioclase, 10 to 12 percent of augite and hornblende, and somewhat less than 10 percent of quartz. The accessory minerals include apatite, magnetite, a trace of zircon, and sphene, in part secondary. In one specimen the sphene constitutes as much as 3 or 4 percent of the rock. The plagioclase consists of well-formed phenocrysts, generally 1 to 2 millimeters long and constituting 15 to 45 percent of the rock, set in a matrix of plagioclase, orthoclase, and quartz so fine-grained that distinction between the two feldspars is difficult. In some specimens the plagioclase is all zoned, some in an oscillatory manner and through the long range from sodic labradorite to sodic oligoclase, whereas in others zoning is uncommon and the plagioclase is uniformly intermediate andesine. These differences, however, do not coincide with the megascopic differences of texture and color mentioned above. In some of the zoned plagioclase crystals, the outer oligoclase zone sends veinlike threads of composition An_{21} into and replacing the calcic core (pl. 9), and such replacement probably accounts for the oligoclase in the sodic phase of the monzonite at Old Hachita. The white parts that outwardly resemble the rock at Old Hachita contain almost pure albite, but these parts are not prominent enough nor extensive enough to be mapped separately. Carlsbad and pericline twinning of the plagioclase crystals are common. The augite and hornblende are in variable proportions, the hornblende in part forming a reaction rim to the augite. The hornblende locally forms characteristic crystals as much as 5 millimeters long. Both hornblende and augite are variably altered to a bluish-green secondary amphibole, some of which consists of pseudomorphic clusters of imperfect crystals. Epidote is present nearly everywhere and includes colorless grains of clinozoisite, generally in the plagioclase, as well as grains of the common green pistacite, some of which was tested optically and found to contain, according to the Winchell chart,[36] about 17 percent of Fe_2O_3, which is almost at the upper limit of Fe_2O_3 in the epidote group.

The following analyses show the chemical composition of the monzonite.

Analyses of monzonite from the Little Hatchet Mountains, N. Mex.

	I	II	III
SiO_2	60.87	61.59	58.76
Al_2O_3	16.16	15.93	16.59
Fe_2O_3	1.02	2.38	2.84
FeO	1.57	2.40	3.37
MgO	2.32	1.91	2.31
CaO	5.72	5.74	5.51
Na_2O	4.47	4.35	4.48
K_2O	3.23	3.40	1.88
H_2O-	.34	.48	.16
H_2O+	.45		1.18
TiO_2	1.04	0.94	1.22
CO_2	.05	.10	.66
P_2O_5	.51	.59	1.21
SO_3	.46	....	....
MnO	.03	.10	.09
FeS_2	1.57	....	....
	99.81	99.89	100.26

I. K. J. Murata, analyst. Light facies of the monzonite, from Broken Jug Pass. Contains pyrite, epidote, and sericite. Plagioclase is zoned An_{10-55}. Sp. gr., 2.696; porosity, 0.84 percent.

II. J. G. Fairchild, analyst. Light facies of the monzonite, from almost exact center of sec. 28, R. 16 W., T. 28 S. Contains epidote and sericite. Plagioclase is zoned An_{10-52}. Sp. gr., 2.695; porosity, 1.21 percent.

III. K. J. Murata, analyst. Dark facies of the monzonite, from SW¼ sec. 34 about 1600 feet southwest of Sylvanite camp. Contains sericite, calcite, chlorite, and epidote. Plagioclase is zoned An_{14-42}. Sp. gr., 2.734; porosity, 0.16 percent.

[36] Winchell, N. H., and Winchell, A. N., Elements of optical mineralogy, pt. 2, p. 355, 1927.

QUARTZ MONZONITE

The quartz monzonite is intrusive into the monzonite (see pl. 9, *C*) and has metamorphosed it in the contact zone. (See p. 59.) It forms three principal masses—one east of Livermore Spring, one north of Sylvanite, and one at the south end of the stock, where the quartz monzonite has come up in part along the contact between the monzonite and the Howells Ridge formation. The mass near Livermore Spring is so cut off by the Copper Dick fault that no inference as to its attitude can be drawn, but the other two masses have their long axis parallel to the concordant boundaries of the stock.

The rock is medium-grained and granitoid and tends to weather to a gravelly aggregate. It contains about 10 percent of hornblende and biotite, in grains and irregular flakes as much as 5 millimeters across, and phenocrysts of plagioclase and minor orthoclase and microcline, all generally 2 to 3 millimeters in length, in a pink-and-white granitoid matrix of variable grain size containing orthoclase, microcline, a little plagioclase, and subordinate quartz. The two feldspars seem on the average to be nearly equal in amount, though their relative proportion varies in different specimens. The plagioclase is commonly intermediate andesine, An_{37-40}, but a few individuals are zoned between calcic andesine and intermediate oligoclase. The hornblende, compared with that in the monzonite, is a pale variety having pleochroism in yellow and in brownish, bluish, and apple green. The biotite is commonly altered to bright-green chlorite pseudomorphs containing tiny granules of sphene and leucoxene, but where fresh it is muddy brown and invariably contains oriented acicular inclusions. The accessory minerals include grains of apatite as much as 2 millimeters in length, magnetite, sphene, and rare zircon. The sphene is very common in some specimens and locally forms a rim to some of the magnetite (ilmenite?) clusters. Epidote is a common alteration constituent, and, as in the monzonite, ranges from colorless clinozoisite to deep yellow and green pistacite.

The hornblende in some specimens is variably replaced by clusters of brownish-green biotite crystals. Flakes of such biotite also are interstitial to the minerals of the groundmass, and threads of it cut veinlike through the rock. In most of the quartz monzonite at the south edge of the stock the original hornblende and brown biotite are completely replaced by this brownish-green biotite, which is so abundant that it darkens the whole mass. Details of this stage and type of alteration are given in the section on metamorphism. (See p. 57.)

Analysis of specimen of quartz monzonite from short tunnel east of Livermore Spring, Little Hatchet Mountains, N. Mex.

[Contains chlorite, sericite, and epidote. Sp. gr., 2.655; porosity, 2.26 percent. K. J. Murata, analyst]

	Percent		Percent		Percent
SiO_2	58.80	CaO	4.81	TiO_2	1.18
Al_2O_3	16.33	Na_2O	4.53	CO_2	.68
Fe_2O_3	3.04	K_2O	3.71	P_2O_5	1.09
FeO	2.40	H_2O-	.48	MnO	.08
MgO	1.48	H_2O+	1.21		99.82

In its essential features this analysis is practically identical with analyses of the monzonite. Nevertheless, and despite the low silica content, the rock seems to contain somewhat more than 10 percent of quartz and is classed as quartz monzonite as a concession to the mineralogy.

MONZONITE DIKES AND SILLS OF THE SYLVANITE AREA

Countless dikes and thin sills of monzonite cut the rocks of the Broken Jug and Howells Ridge formations bordering the Sylvanite stock. Many of them are tongues, apophyses, of the monzonite facies of the stock, but many others have no such connection, unless it be below the surface, and may be satellite bodies of slightly later age.

The unconnected dikes and sills closely resemble the darker facies of the monzonite, though they are perhaps finer-grained, slightly more porphyritic, and more consistently gray. They likewise are petrographically similar to the rocks of the stock in that they contain phenocrysts of andesine, or of feldspar zoned from andesine to oligoclase, and a ferromagnesian mineral in a matrix of orthoclase and subordinate quartz. Some, in which biotite is the only ferromagnesian mineral, may be related to the quartz monzonite phase of the stock; others, in which hornblende is the ferromagnesian mineral, are presumably related to the monzonite. None have apatite phenocrysts such as characterize the monzonite porphyry dikes of the Eureka area.

PETROGRAPHIC RELATIONS BETWEEN THE SYLVANITE AND OLD HACHITA STOCKS

As mentioned in the description of the Sylvanite stock, the structure of the Little Hatchet Mountains indicates that the stock at Old Hachita is the faulted-off top part of the stock at Sylvanite, and it seems appropriate here to examine the petrography of the two in that light.

The monzonite parts of both stocks are essentially identical, and the two bodies would have been described together were it not for the preponderance of the sodic facies at Old Hachita and the differences in the monzonite dikes satellite to each. The two groups of dikes, however, also are much alike petrographically, and aside from the presence or absence of apatite phenocrysts, differ chiefly in the fact that the dikes at Old Hachita contain albite as the plagioclase, in conformity with the sodic plagioclase of most of the parent mass, whereas those at Sylvanite contain andesine, in conformity with their parent rock. The difference between the two groups of dikes therefore is essentially the same as the difference between the parent masses, namely, a difference in the plagioclase, and may be due in both stocks and dikes to alteration of the originally more calcic plagioclase by sodic solutions, for geologists seem generally agreed that practically pure albite, such as is present in some of the rock, is never magmatic. If the parent masses were originally parts of the same body, there must have been a concentration of sodic juices toward the tip of the stock and, to judge from the albitic spots and local veinlike replacement of original plagioclase by oligoclase in the Sylvanite monzonite, the part now exposed at Sylvanite must have been close to the bottom of the alteration chamber.

This interpretation assumes that the replacement by albite and oligoclase were parts of the same process, to which there probably can be no firm objection. Physical chemists familiar with such problems have recognized for some time that, theoretically, plagioclase of a composition normally considered magmatic can be formed in a hydrothermal environment.[37] The recently published results of hydrothermal experiments by Eskola[38] and his associates corroborate this viewpoint, for not only have they produced material whose indices of refraction they interpreted as indicating pure albite, but in other experiments at higher temperatures and with lower soda-lime and silica-lime ratios they have also repeatedly produced oligoclase of various compositions and, in one experiment, andesine An_{42}. The assumption, however, that both albite and oligoclase in the Sylvanite-Old Hachita stock were formed by the same process does not necessarily imply that the entire process was hydrothermal; actually the alteration seems to have started somewhat before the true hydrothermal stage, because unless the replacement of some original zoned calcic plagioclase by intermediate oligoclase identical in composition with that in the outer pyrogenetic zone (see p. 32) is an outright coincidence, it would seem to indicate a point in the formation of the rock on the border between the pyrogenetic and deuteric stages. It seems reasonable to conclude, therefore, that the alteration by sodic juices in the tip of the Sylvanite-Old Hachita stock began while the crystallization system was still essentially magmatic but in which the volatiles were abundant enough to characterize a hydrothermal type of reaction, and continued to a definitely hydrothermal stage, or open system, in which albite was formed. That volatile constituents were abundantly present at some such stage is further indicated by the fact that contact metamorphism began before complete consolidation of the monzonite (see p. 56), implying an escape of volatiles during an early stage, and the continuity of the process is suggested by the presence of secondary plagioclase of different compositions between practically pure albite and the deuteric plagioclase of composition An_{21}; for example, the albite in the monzonite porphyry dikes at Old Hachita ranges from An_3 to An_8 and the secondary plagioclase in the sodic facies of the monzonite ranges from about An_2 to An_{15}, and in the stock at Sylvanite pure albite and oligoclase An_{20} or An_{21} have been identified.

THE GRANITE PASS COMPOSITE STOCK

The south tip of the Little Hatchet Mountains, from Granite Pass to the southernmost hill at Hatchet Gap, consists of an intrusive mass composed of three varieties of granite distinctly different in both appearance and age. The distribution of the three varieties is shown on the geologic map. (See pl. 1.) The total area exposed is about 6 square miles.

The mass is intrusive into the quartzite and limestone of uncertain age at Hatchet Gap and into the Corbett and Playas Peak formations, which are metamorphosed in the contact zone. At Hatchet Gap the small stretch of exposed contact is concordant with the quartzite and limestone and the granite is closely jointed parallel to the contact. Except for minor irregularities, most of the contact with the Corbett sandstone is parallel with the strike and, so far as can be observed, also with the dip of the beds, and the small outcrop in sec. 21 forms a concordant dip slope on beds of the Playas Peak formation. Other parts of the small amount of exposed contact in that area also are concordant. As opposed to these concordant parts, fully a mile of the contact at and south of the Corbett Ranch, as well as most of the contact at the east edge of Granite Pass, is sharply crosscutting. Thus the mass as a whole may have an attitude and shape similar to the stock at Sylvanite, that is, a slab- or board-shaped mass lying sill-like within the sediments, with a floor and a roof but with blunt sides; if so, the thickness of the mass, measured normal to the contacts, would be about 11,000 feet. At the extreme south tip, the granite is faulted against the Magdalena limestone of the Big Hatchet Mountains.

The three varieties of granite that constitute the mass—porphyritic granite, aplitic granite, and seriate porphyritic granite—are described in the following paragraphs.

PORPHYRITIC GRANITE

The earliest of the three varieties is a dark resistant porphyritic rock that occupies the rugged south tip of the range, where it constitutes almost two-thirds of the exposed mass. The fresh rock is a gray granite containing rounded or ovoid phenocrysts of gray feldspar ¼ to ½ inch across in a granitoid matrix of feldspar and quartz. The feldspar includes orthoclase, microperthite, and a little albite, apparently An_{10}. The texture is somewhat like that of a special group of pre-Cambrian granites in Finland and Sweden and in the Ural Mountains of Russia known as "rapikivi granites,"[39] though the orthoclase and perthite phenocrysts do not have oligoclase shells such as characterize the typical rapikivi rocks. Thin sections suggest vaguely that the albite may be a late mineral. A thin section of a specimen from the south part or roof of the mass, at Hatchet Gap, where the rapikivi-like texture is missing, contains no albite at all, and much of the quartz and perthite are graphically intergrown, with perthite replacing quartz. (See p. 59.)

Scattered through the rock are large flakes of black biotite and pockets of minutely crystalline biotite. The minute crystals are pale brown to green in thin section and evidently have been formed through recrystallization of the darker brown mica

[37] Oral communications from J. F. Schairer and Earl Ingerson of the Carnegie Geophysical Laboratory.

[38] Eskola, Pentni, Vuoristo, U., and Rankana, K., An experimental illustration of the spilite problem: Soc. Geol. Finlande, Comptes Rendus, Ext. 9, 1935.

[39] Sederholm, J. J., On orbicular granites, spotted and nodular granites, etc., and on the rapikivi texture: Comm. geol. Finlande Bull. 83, 1928. Zavaritsky, A., Petrography of the Berdiaush pluton: Russ. Cent. Geol. and Prosp. Inst. Trans., vol. 96, 1937. (With English summary.)

of the large flakes. They tend to be grouped at the edges of the large flakes and to form isolated clusters that presumably represent complete recrystallization, and some of the new mica extends outward from the clusters in minute veinlets. This alteration, apparently endomorphic, is discussed more fully on p. 57. The accessory minerals of the rock include apatite, zircon, sphene, and magnetite, some of which seems to have resulted from recrystallization of the biotite. Sericite is present but apparently uncommon.

Weathering darkens the rock considerably and so accentuates the texture that the rock, because of the large rounded phenocrysts, looks surprisingly like a pebbly conglomerate. (See pl. 9, *D*.)

APLITIC GRANITE

A little fine-grained tan-colored granite intrudes the porphyritic variety at the west edge of the range and just south of the contact between the porphyritic and seriate porphyritic varieties. Because of the scale of the geologic map, this rock is shown as a comparatively continuous mass with dike extensions, but in detail it seems more nearly to consist of a group of closely-spaced and interwoven dikes. The borders are sheeted at many places, and the contacts are frozen and generally quite sharp, but locally there is a transition zone as much as 4 inches wide that contains scattered phenocrysts of the porphyritic granite in a groundmass of the fine-grained rock. The mass lies entirely within the porphyritic granite, but one of the dikes extends over to the contact between that rock and the seriate porphyritic granite, dikelets of which seem to cut the aplitic granite.

The rock consists of a granitic intergrowth of quartz, perthite, and a very little albite-oligoclase in grains that average about 1 millimeter across. A few shreds of brown biotite are scattered through the rock, and the accessory minerals include apatite, magnetite, zircon, and sphene. Some of the biotite is like the late variety in the porphyritic granite and like it occurs in tiny flakes along grain boundaries and as veinlets that indiscriminately cut quartz and feldspar. Part of the sphene also lies along cross-cutting veinlets.

The dikelike form of the rock and its texture, grain, appearance, and composition (pl. 4) suggest that it may be an aplitic phase of the porphyritic granite.

SERIATE PORPHYRITIC GRANITE

The north part of the stock, from a mile south of the Granite Pass road, where it is in contact with the porphyritic granite, to about a third of a mile north of the road, where it is largely in contact with the Corbett sandstone, consists of a pink granite that appears dazzling white under the sun. A dike of the same rock crosses the Corbett and Playas Peak formations about a mile to the north. The granite weathers to friable gravel, and its great susceptibility to erosion is shown by the cutting of Granite Pass nearly to the level of Hachita and Playas valleys. The higher parts have assumed fantastic bouldery shapes or have broken down into masses of loose boulders. (See pl. 10, *A*.)

The rock is porphyritic and consists essentially of grains of quartz reaching ¼ inch in diameter and crystals of pink orthoclase and microcline as much as an inch in length in a continuous graded series. A few zoned crystals of oligoclase-andesine are present with 5 to 10 percent of corroded book-like plates of brown biotite, 1 to 2 millimeters across. The accessory minerals are apatite, magnetite, and zircon. The alteration minerals are sericite, chlorite, and calcite.

Dikelike offshoots of this granite into the porphyritic variety and a chilled contact selvage against the porphyritic granite prove the relative ages of the two rocks. It will be noted from the geologic map that the contact between the two rocks is roughly parallel to the floor of the stock as a whole, and perhaps the seriate porphyritic granite was injected along the floor of the earlier variety.

LAMPROPHYRE AND APLITE DIKES

Literally hundreds of lamprophyre dikes are present in the Little Hatchet Mountains. They are particularly abundant in the Sylvanite area, where some seem to have a sill form and where they are accompanied by aplite dikes. Both rocks invade the stocks and the enclosing sediments, and both are of considerable interest because of their association with the ore deposits of the Sylvanite area. The Gold Hill vein lies within an aplite dike, and the rest of the veins of the district almost all lie along lamprophyre dikes. The replacement deposit at the Copper Dick mine likewise is localized along a lamprophyre dike.

The major aplite dikes are prominent features and are shown on the geologic map. The lamprophyre dikes, however, are much too small to be indicated, for they are generally much less than 100 feet in length and only 15 feet or less in thickness.

The aplite dikes are Hill's "syenite dikes." [40] The thin sections examined disclose irregularly intergrown grains of orthoclase and quartz with minor albite and a few flakes of biotite. The lamprophyre dikes include several varieties. They are commonly dark-gray to black sugar-textured, fine-grained rocks in which can be seen the shimmer of tiny flakes of biotite and of needles of hornblende, though some are even too dense for that. Some varieties are lighter in color and a little coarser in grain, and contain prominent needlelike phenocrysts of brown hornblende 1 to 5 millimeters in length. A few dikes are comparatively coarse-grained and contain such large flakes of shiny biotite that they at once suggest the derivation of the name lamprophyre, which means "shining porphyry." Many of the dikes, and perhaps the greater number, are mineralogically intermediate between the varieties known as spessartite (hornblende-plagioclase lamprophyre) and kersantite (biotite-plagioclase lamprophyre), but a large number of them, including all the light-colored dikes, are distinctly hornblende lamprophyres with differing proportions of orthoclase and plagioclase, so that some would be called vogesite and others spessartite, spessartite perhaps being the commoner. The plagioclase is generally labradorite, but some

[40] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 340, 1910.

specimens contain andesine or crystals zoned from labradorite to oligoclase. A few grains of augite are present in some dikes, and one dike of augite lamprophyre was recognized. The augite commonly has a reaction rim of hornblende and the hornblende a reaction rim of biotite. Changes from one variety of lamprophyre to another within a single dike are present.

Many of the densest and darkest of the lamprophyre dikes outwardly resemble parts of the Hidalgo volcanics and some of the Quaternary basalt dikes, and they are conveniently called trap dikes for a field classification. In some, particularly in the Eureka area, weathering has so emphasized the slender plagioclase crystals that the rock looks confusingly like some Quaternary diabase dikes of the area; however, a little pyrite or epidote may generally be seen in the lamprophyre dikes, whereas the Quaternary dikes are unmineralized. This feature was used in field identification where the late or early age of the dike was not clear; on the other hand, pyrite and epidote are not everywhere obvious, and microscopic examination would have to be resorted to for strict identification. Some of the trap dikes cannot be distinguished from some of the black metamorphosed sedimentary rocks without microscopic examination.

Though all belong to the same general stage of activity—the interval between injection of the stocks and formation of the ore deposits—not all aplite nor all lamprophyre dikes are of exactly the same age. At the Little Mildred mine an aplite dike is clearly cut by a smaller dike of lamprophyre (see pl. 25), and at Granite Pass one of the aplite dikes is crossed by a dike of spessartite; on the other hand, augite and biotite-bearing vogesite dikes in the porphyritic granite to the south are cut by aplite-pegmatite stringers. On the west side of Sylvanite arroyo, three-fourths of a mile above Sylvanite camp, a dike of the coarse-grained augite-bearing spessartite-kersantite seems to be crossed by an augite-free sugar-textured dike of the same variety.

TERTIARY (MIOCENE?) ROCKS

The Tertiary rocks include lava flows and underlying pyroclastic rocks; latite dikes and sills, in part earlier than the pyroclastic rocks and in part probably later and constituting the intrusive equivalent of the earliest of the flows; dikes, sills, and plugs of felsite; and pods of granite that lie along the Copper Dick fault. A little conglomerate is interbedded with the pyroclastic rocks at one place, but it was not separated in mapping. All these rocks are later than the ore deposits of the area—and, by analogy with other districts of the general region, at least the extrusive rocks are also later than their oxidation and erosion—but the Tertiary rocks themselves are faintly mineralized. (See p. 82.)

The extrusive rocks occupy the high cliffs west and south of the Skunk Ranch and the northwestward-trending ridges of the Coyote Hills. (See pl. 7, *A*.) They are parts of the thick extensive blanket that covers most of the mountainous areas of the general region and, to judge from the regional distribution and generally great thickness, at one time may have covered the full area of the Little Hatchet Mountains. Some of the formations can be correlated in detail with rocks of the surrounding areas. The same formation of basal pyroclastics can be traced through the Pyramid Mountains of the Lordsburg quadrangle,[41] and petrographically similar pyroclastic rocks form the base of the Tertiary extrusive rocks in the Alamo-Hueco (Dog) Mountains, between the Big Hatchet Mountains and the international boundary. The earliest flows and some of the latite dikes are petrographically the same as latite flows, dikes, and volcanic necks in the Pyramid Mountains. Some of the dikes and necks near Leitendorf Camp in the northern part of the Pyramid Mountains are known to be the intrusive equivalents of the flows;[42] other similar dikes, plugs, and flows crop out at various places between there and the Little Hatchet Mountains, and no hesitancy is felt in correlating them with one another and with those in the Little Hatchets.

A later lava flow in the Little Hatchet Mountains region is very like the quartz latite flows of the Pyramid range and the quartz latite flows of the Santa Rita region.[43] Quartz latite flows that are megascopically identical with this rock seem to make up much of the Animas range west of Playas Valley.

The felsite and earlier latite dikes closely resemble the felsite and quartz latite dikes of the Lordsburg district;[44] and the quartz latite dikes of the Lordsburg district are similar to some quartz latite dikes and plugs of the Central (Santa Rita) district,[45] although there the dikes are younger than the pyroclastic rocks and bear the same relation to the flows as do the later latite dikes of the Pyramid and Little Hatchet Mountains. These correlations lead to the tentative belief that the earlier and later latite dikes of the Little Hatchet Mountains are genetically closely related, even though one is younger than the pyroclastic rocks and the other older, even older than at least part of the erosion interval that preceded their deposition. The probability of a genetic relationship is supported by the close petrographic and textural similarity of the two rocks, as indicated by the detailed descriptions given below. For southwestern New Mexico the felsite and earlier latite seem to constitute a link between the late Cretaceous or early Tertiary period of deep-seated activity and the Miocene (?) volcanic stage. (See pp. 38, 42.)

LATITE DIKES AND SILLS

Under this heading are included the earlier and later latites mentioned above. The dikes and sills of these rocks are not abundant, but they are of particular interest because of their bearing on the igneous and hydrothermal history of the region. The principal members of both groups are shown on the geologic map, though not differentiated.

The widest of the dikes classed as earlier latite,

[41] Lasky, S. G., Geology and ore deposits of the Lordsburg mining district, Hidalgo County, N. Mex.: U. S. Geol. Survey Bull. 885, pp. 16–17, 1938.
[42] Lasky, S. G., Idem, p. 17.
[43] Lasky, S. G., Geology and ore deposits of the Bayard area, Central mining district, N. Mex.: U. S. Geol. Survey Bull. 870, pp. 44–45, 1936.
[44] Lasky, S. G., op. cit. (Bull. 885), pp. 15, 16.

one about 80 feet across, cuts the diorite sills and the Broken Jug limestone on the slope above the King vein near Old Hachita and extends eastward for half a mile to the point where it passes under the wash. (See pl. 5.) Identical rock crops out three-fourths of a mile to the east along the strike. A second dike extends from the low saddle just west of the American mine, at the end line between the Oregon and Alaska claims, northwestward through the basal breccia of the Hidalgo volcanics to the National fault, cutting across the Eighth of March vein on its way. A third dike, not shown on the map, crops out in sec. 26, T. 27 S., R. 16 W., near the western tip of the breccia layer in the Ringbone shale. In the Sylvanite area, an earlier latite dike nearly a mile long curls westward up the ridge south of the Copper Dick mine, where it forms a conspicuous white streak against the dark background of the metamorphosed Broken Jug limestone. Farther west, another latite dike of equal length cuts the monzonite and the metamorphosed Broken Jug limestone along the draw leading westward from the Buckhorn mine. (See pl. 20.) A small dike classed as earlier latite, not shown on the map, crops out on the slope above the Little Mildred mine and was crossed in the lower tunnel. (See pl. 25.)

The earlier latite dikes tend to be strongly sheeted at the borders. They are generally chalky white, apparently as the result of bleaching, and contain phenocrysts of sericitized orthoclase and sodic plagioclase and flakes of partly chloritized and bleached biotite in a microgranitic intergrowth of quartz, orthoclase, and, in some specimens, plagioclase. The feldspar phenocrysts are rarely more than 2 millimeters in length and tend to be sharp-cornered euhedral crystals. Most of the rock contains numerous small corroded phenocrysts of quartz and is really quartz latite, but quartz is locally sparse or absent.

Several sills similar to the darker and quartz-free parts of the dikes crop out in the Playas Peak formation in the Eureka area. The most prominent, 20 to 55 feet thick, follows the top of the formation for nearly 2 miles to the edge of the cap of Tertiary volcanic breccia, under which it passes. (See pl. 1.) This rock contains slender white phenocrysts of sodic oligoclase, only 0.5 millimeter thick but fully 7 millimeters long, set in a grayish-green fine-grained groundmass that the microscope shows to be an indistinct intergrowth of orthoclase and quartz. As in the dikes, small flakes of bleached biotite are present.

The rock classed as the later latite forms, in effect, a single prominent red dike, which passes through the Hall Ranch and extends the nearly 4 miles across the range. It is generally about 40 feet wide and cuts through the bleached and oxidized monzonite west of Cottonwood Spring and across several oxidized veins that lie in its path. Several small dikes of the same rock parallel the main body. Near the edges of the range the dike is discontinuous, but the several segments exposed doubtless are parts of the same dike. The rock contains sericitized phenocrysts and clusters of albite-oligoclase between 1 and 4 millimeters in length, and flakes of chloritized biotite in a pink to buff micrographic groundmass of quartz and orthoclase with microlites of plagioclase. It closely resembles the Tertiary lava flows overlying the pyroclastic rocks west of the Skunk Ranch and some of that in the Coyote Hills, differing from the flow rock only in having a slightly coarser groundmass and no flow banding, and may be the dike equivalent. (See p. 37.)

Except for color and the great difference in degree of alteration, the earlier and later latites are nearly identical, and the age distinction is based on correlation with similar dikes in the Pyramid Mountains. (See pp. 32, 42.) Wherever seen in contact with the pyroclastic rocks there, the bleached dikes classed as earlier latite underlie the pyroclastics, and the fresh, buff to red dikes and plugs classed as later latite cut the pyroclastics.

FELSITE

Two small plugs and several thin dikes or sills of felsite crop out in the Eureka district. The two plugs cut the Howells Ridge formation at the edge of Playas Valley and are largely bordered by the valley fill. Directly east of the plugs several narrow streaks of the felsite cut the Howells Ridge formation, and three others crop out at and near Old Hachita, where they cut rocks as young as the monzonite and where one of them crosses a prominent gossan just east of the houses. Locally these felsite bodies clearly crosscut the enclosing formations as dikes, but for the most part they parallel the strike of the beds and may be sills, as suggested by the attitude of the paper-thin sheeting that almost invariably characterizes the border zones.

The rock of the dikes and sills is white, generally porcelainlike, and brittle, and the border zones have a ropy appearance, due to the sheeting. A thin section of the coarser central part of one dike—or sill—discloses a few phenocrysts of quartz, albite, and orthoclase, all less than half a millimeter in diameter, in a partly spherulitic, partly micrographic groundmass containing many shreds of sericite. The rock of the plugs is essentially the same as that of the dikes, though reddish or buff-colored and marked with tiny white spots. These spots, as shown by the microscope, are feathery spherulites and lie in a very fine-grained groundmass containing shreds of sericite. The reddish color of the rock is due to limonitic stain.

As indicated by the relationships described above, the age of the felsite with respect to the veins and to the earlier rocks is identical with that of the bleached (earlier) latite dikes, but the exact relationship between the felsite and latite dikes is not known.

EXTRUSIVE ROCKS

PYROCLASTIC ROCKS

These rocks comprise most of the Tertiary volcanic material exposed in the area, the formerly overlying flows having been stripped away or, where present, being largely covered with valley fill. The pyroclastic material was deposited on the eroded and hilly surface of the folded Cretaceous rocks, and consequently its thickness ranges widely. In the

Coyote Hills the thickness ranges from about 1,000 to 1,700 feet or more, the thicker part occupying a broad depression in the old surface. Near the Skunk Ranch the maximum thickness is about 800 feet in both the largest exposures, and this must be nearly the original thickness because the lava that caps these rocks to the west, in sec. 18, rests upon the breccia layer that forms the top of the 800-foot part. In sec. 18, however, the pyroclastic rocks are only about 200 feet thick. On the assumption that these differences of thickness are due largely, if not wholly, to the irregular erosion surface at the base, the relief of that surface must have been at least 1,500 feet, that is, the difference between the minimum thickness of 200 feet in the Skunk Ranch area and the maximum of about 1,700 feet in the Coyote Hills. The minor irregularities of the contact between the pyroclastic and Cretaceous rocks suggest that the gullies and valleys of the old surface had a depth of 100 to 200 feet.

The pyroclastic rocks consist at some places predominantly of breccia, elsewhere of tuff. In the Skunk Ranch area they consist almost entirely of rudely layered white, pink, and brown rhyolite breccia and lithic tuff whose fragments range in size from the finest dust to a maximum of 2½ inches. The predominant light color is due to an abundance of chalky-white sandy fine-grained porphyritic rock, which the microscope shows to contain phenocrysts of quartz, sanidine, and very minor albite in a microspherulitic groundmass crowded with the hair-like crystals called trichites. Other fragments include gray to red fine-grained rhyolites, and a few red oxidized pieces whose residual texture suggests an andesitic rock. Grains of quartz, sanidine, black and bronze-colored biotite, and a little sodic plagioclase are common, and glass shards are generally present. These crystalline and glassy materials predominate over the rock fragments in some layers or parts of them, and the rock then is a crystal-vitric tuff, generally red or brown, containing the crystals in a typical vitroclastic groundmass. The chalky-white parts seem to belong to the "Katmai-type" tuff, as defined by Fenner;[46] megascopically the rock of these parts seems identical with the hand specimens exhibited by Fenner, in which the fragments were labelled "pneumatolitically recrystallized inclusions of glass." According to Fenner, the Katmai-type tuff originates from lava that was not ejected in the pyroclastic form, but that reached the surface while still containing much gas, with expulsion of the gas and consequent fragmentation as the lava flowed along the surface.

A little white volcanic sand, hard and compact, is present locally at the top of the breccia in secs. 6 and 7, T. 28 S., R. 16 W. Similar sand, associated with volcanic gravel, the total thickness not exceeding 25 feet, lies near the base of the breccia at the easternmost tip of the largest exposure of the Skunk Ranch area. A flow or sill of greenish-gray hornblende latite, not differentiated on the geologic map, lies above the sand and gravel there, and two small plugs of the same rock crop out at the north edge of the cliffs at Playas Peak, one in the Playas Peak formation and the other cutting both that formation and the pyroclastic rocks.

[46] Fenner, C .N., Tuffs and other volcanic deposits of Katmai and Yellowstone Park. Paper presented before Am. Geophys. Union, Sec. Volcanology, Washington, D. C., April, 1937.

In the Coyote Hills the pyroclastic rocks consist entirely of rhyolitic tuffs. Several varieties are present, distributed in layers that are persistent over most of that area. At the thickest part of the section, due northeast of Pothook station, the base of the formation consists of roughly sorted conglomerate containing rounded pebbles of sandstone, Lower Cretaceous and Pennsylvanian limestones, the diorite of the earliest sills, and latite like that of the sills in the Playas Peak formation, in an angular matrix of similar material mixed with a good deal of the underlying Ringbone shale. Above this is a thick section of white gravelly ash containing several lenses of conglomerate in the lower part. The pebbles of the conglomerate are like those of the basal layer and are cemented with a red tuffaceous limestone. The thickness of the conglomerate lenses, including some interbedded layers of white to red sandy limestone, ranges from 2 to 20 feet. Above the ash is a layer of hard vitric tuff that forms the ridge of these hills and that resembles some of the welded tuff in southeastern Idaho as described by Mansfield and Ross.[47] It is a gray to lavender stony material spotted with crystals of bronze-colored biotite and with rock fragments that predominantly are flow-streaked rhyolite. Distributed through the rock are porous streaks a fraction of an inch long, made up of crystalline fibers set at right angles to parallel walls. In the southern part of the exposure these fibrous streaks are accompanied by streaks and pockets of spherulites. These spherulite pockets are as much as 5 inches long and 1 inch thick, and individual spherulites are as much as ¾ inch in diameter. The groundmass is a devitrified crystalline and fibrous aggregate in which the vitroclastic structure is preserved and in which the original shards appear to have been flattened out. Between this rock and the overlying lava are several layers of vitric and crystal-vitric tuff and pumiceous ash. The following section indicates the detailed variations.

Composite section of Tertiary pyroclastic rocks in the Coyote Hills

[Begins about 300 feet northwest of S. ¼ cor. sec. 3, T. 27 S., R. 16 W., and ends near east-center edge]

	Feet
Quartz latite flow.	
Ash, soft mottled purple and white	28
Vitric tuff, blue-white, containing a few pieces of brown felsite, ¼ to ½ inch across, as well as crystals of quartz, sanidine, biotite, and minor plagioclase	137
Ashy tuff, soft, mottled pink and white	55
Vitric tuff, brown, compact, fine-grained	24
Ash, soft, white to pink	50
Vitric tuff, bluish, hard, containing fragments of white felsophyre and brown felsitic rock as much as 1 inch across and crystals of quartz, sanidine, biotite, and plagioclase	42
Vitric tuff, pink, soft, porous, containing only a few grains of quartz, feldspar, and rare biotite, and patches of white pumice	102
Crystal-vitric tuff, pale-brown, with quartz, sanidine, opalescent plagioclase, and biotite, in a vitroclastic groundmass. Contains many small angular cavities apparently formed by leaching out of crystals, but otherwise resembles the crystal-vitric tuffs near Skunk Ranch	143
Welded tuff (see text)	205

[47] Mansfield, G. R., and Ross, C. S., Welded rhyolitic tuffs in southeastern Idaho: Am. Geophys. Union Trans., pt. 1, pp. 308–321, 1935.

Concealed by talus	230
Ash, white, soft, like that below but less gravelly	64
Tuff, dark brown, hard, compact, sandy and limy	15
Ash, white, compact to incoherent, with layers of water-worn volcanic gravel	202
Porcellaneous tuff, white to pink, hard	20
Pumiceous ash, white, incoherent, gravelly, and slightly bentonitic. In lower part contains as much as 50 percent of rock pieces 1/16 to 1½ inches across including rhyolite, limestone, and shale, the largest pieces well rounded. Crystals of black biotite prominent in upper part	316
Conglomerate (see text)	37
	1,670

Angular unconformity.
Ringbone shale.

The long hill south of Vista siding is composed of interlayed white tuff and pumiceous ash overlain by purplish crystal-vitric tuff nearly identical with some of the layers of the Skunk Ranch area and containing a notable amount of opalescent albite in addition to the quartz, sanidine, and ever-present biotite. The large hill next southeast likewise is floored with white ashy tuff, above which is a layered succession of hard, brick-red volcanic sand and fine- to coarse-grained breccia. Most fragments of the breccia seem to be the red or purple tuff with the opalescent feldspar. Present also are fragments of light-colored flow-streaked rhyolite, brown glassy rhyolite having small phenocrysts of biotite and white feldspar, cherty, jaspery, and glassy fragments, red oxidized rock, and rare pieces of diabase.

LAVAS

Two varieties of lava locally overlie the pyroclastic rocks. In the Skunk Ranch area (pl. 1) is a red to light chocolate brown latite, locally flow-streaked and containing a few medium-grained (1 to 3 mm.) phenocrysts of white sericitized sodic plagioclase and spangles of shiny black biotite in an aphanitic intergrowth of quartz, orthoclase, and microlites of plagioclase. A little glass is present, as well as considerable iron-oxide dust to which the red color of the rock is due. The other variety is found in the Coyote Hills. It is a rough-surfaced quartz latite containing 30 percent or so of conspicuous phenocrysts of quartz, glittering sanidine, black biotite, and sodic plagioclase in a partly spherulitic, partly trichitic groundmass of red glass.

Both varieties have been traced through the part of the Coyote Hills beyond the area mapped and through the Pyramid Mountains, and wherever found together the latite is at or within 50 feet of the top of the pyroclastics and the quartz latite is above. The maximum thickness of any exposure in the area mapped is about 300 feet.

GRANITE ALONG THE COPPER DICK FAULT

Several pod-shaped masses of friable, coarse-grained white albite granite crop out at intervals in and near the Copper Dick fault along the 2-mile stretch occupied by that fault's S-shaped bend. (See pl. 1.) East of Livermore Spring one of the masses seals the Copper Dick fault, and others lie 10 to 50 feet from the fault within the dragged beds of the hanging wall. Those west of the spring lie along the contact between the Playas Peak and Skunk Ranch formations, 10 to 250 feet in the hanging wall of the fault. The serrated intrusive contact of some of the bodies is clearly exposed.

Unquestionably the granite was injected after the rocks in the walls of the Copper Dick fault had largely attained their present positions, but it is older than the final movement because at some places it is itself crushed and brecciated. (See pl. 10, *B*.) Being later than the major movement on the Copper Dick fault, the granite is younger than the rocks displaced by the fault and consequently younger than the Sylvanite and Granite Pass stocks and their associated aplite and lamprophyre dikes. Furthermore, the major displacement along the Copper Dick fault took place after the mineral deposits were formed (see p. 43), and consequently the granite was injected later than the main epoch of mineralization. On the other hand, the dragged limestone beds of the Playas Peak formation along the fault are at places completely silicified, and near those places stringers of quartz cut the granite. The granite, therefore, occupies about the same position in the geologic history of the range as the Miocene (?) volcanic rocks, in that it is later than the late Cretaceous or early Tertiary intrusive rocks, later than the main period of mineralization, and later than some faulting, but is itself faintly mineralized and involved in the latest fault movement. The Copper Dick fault is of such great magnitude that it might well have tapped the reservoir from which the Miocene (?) volcanic rocks came and might have permitted the reservoir material to rise into the fault and crystallize as granite.

QUATERNARY ROCKS

BASALT

A dike of diabase, not shown on the map, cuts the basal Miocene (?) tuff at the west edge of hill 4997 southeast of Vista siding, and a larger and more irregular mass of brownish-black trap cuts the volcanic breccia in sec. 19 southwest of the Skunk Ranch. These rocks probably represent the Pleistocene basalt flows (*malpais*), that are widespread throughout southwestern New Mexico.[48] Both croppings outwardly resemble some of the lamprophyre dikes, and more dikes of Quaternary age may be present than the two mentioned. (See p. 34.)

HIGH ALLUVIUM

The term "high alluvium" refers to patches of old gravel scattered through the range and trenched by the present drainage. The largest and most conspicuous are shown on the geologic map. Some of the gravel is perched along the walls of arroyos or covers the adjacent ridges, and some of it forms a shallow apron over comparatively large areas. Outcrops of bedrock here and there and the relation of the gravel to the topography show that nowhere can the gravel be very deep, probably 20 feet at the most and generally much less.

The high alluvium is part of a once more extensive layer of gravel related to an older drainage level 20 to 30 feet above the present one but following the same lines. The broader patches are topographically continuous with rock-cut benches that evidently at one time also were covered with gravel; and the

[48] Schwennesen, A. T., Ground water in the Animas, Playas, Hachita, and San Luis basins, N. Mex.: U. S. Geol. Survey Water-Supply Paper 422, pp. 35–36, 1918.

benches and gravel patches together form a dissected pediment rimming the range, as described in the final paragraphs of the section on surface features. The gravel of the high alluvium invariably is made up of material derived from the hills bordering the pediment, and none of it appears to have traveled more than the short distance thus implied. It is generally unconsolidated, but at places is well cemented with caliche.

VALLEY FILL

The character of the material that fills the valleys bordering the range has been described by A. T. Schwennesen in Water-Supply Paper 422 of the Federal Geological Survey,[49] and the description need not be repeated here.

Information on the thickness of the valley fill is indefinite. As pointed out by Schwennesen, the topography of the bedrock is doubtless irregular, and consequently the thickness of the fill must differ from place to place. Wells have been put down to considerable depths in both Playas and Hachita Valleys, but none penetrate bedrock. The deepest wells for which reliable records are available are the old Winkler well in section 7, R. 16 W., T. 30 S., near the axis of Playas Valley and west of Hatchet Gap and reaching a depth of 836 feet, and a 695-foot railroad well at Hachita.[50] A well in section 16, R. 17 W., T. 29 S. in Playas Valley is said to be between 1,000 and 1,100 feet deep. Other wells in Playas Valley range in depth from about 40 to 350 feet, and others down the axial line of Hachita Valley from 141 to about 350 feet.[51]

Although the surface exposures of the valley fill are of Quaternary age, Pleistocene to Recent, the lower parts may be of upper Pliocene (Tertiary) age.[52]

REGIONAL COMPARISONS OF IGNEOUS AND MINERALIZATION SEQUENCES

A number of points of similarity between the igneous rocks of the Little Hatchet Mountains and those of the Lordsburg and Santa Rita mining districts have been mentioned at several places in preceding pages, and it seems appropriate at this place to summarize those comparisons and to indicate the general parallelism in the igneous and mineralization history of the three districts.

This summary is shown in figure 4, from which two conclusions of regional interest may be drawn. One is that the igneous history of the Little Hatchet Mountains is a blend between that of the Lordsburg

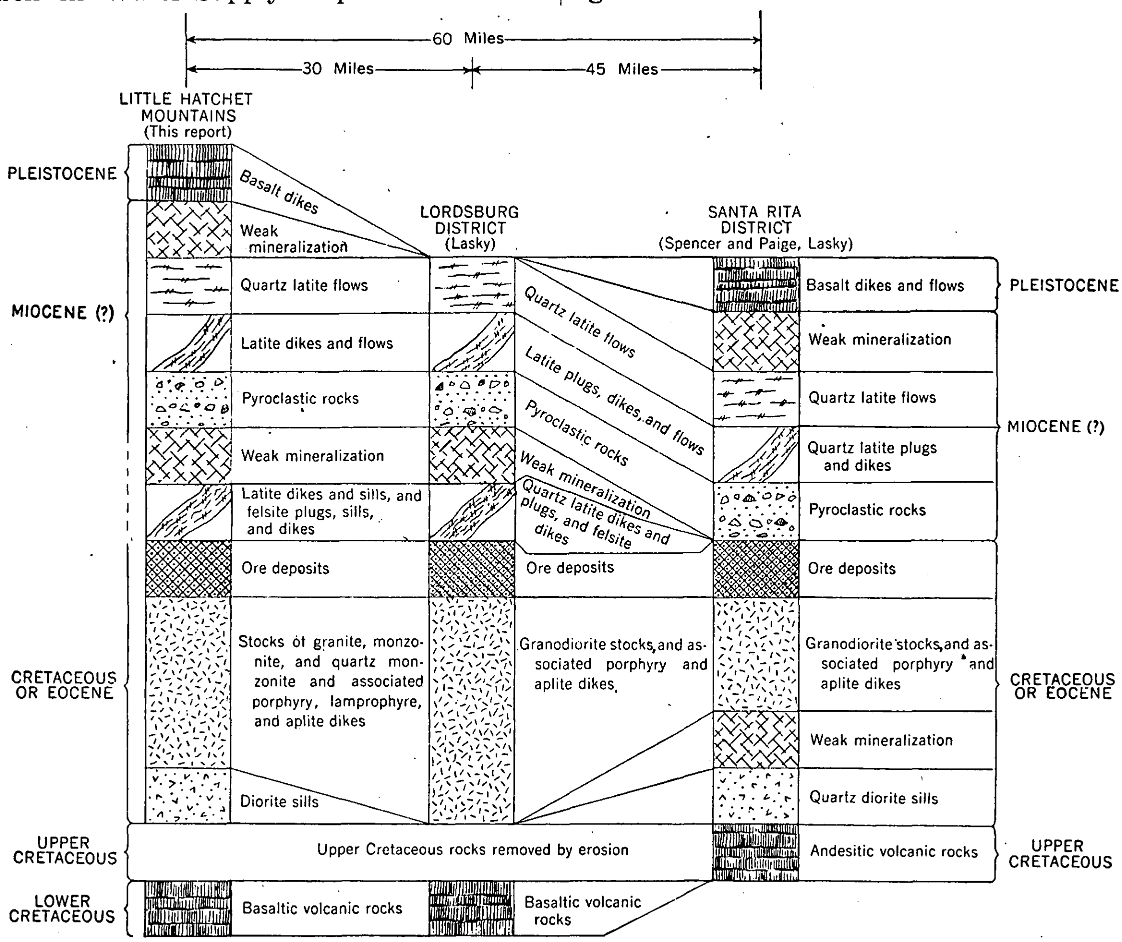


FIGURE 4.—Graphic comparison of igneous and mineralization sequences in the Little Hatchet Mountains and in the Lordsburg and Santa Rita mining districts. Diagram is designed to show sequences only; size of blocks bears no relation to thickness or mass of formation or to duration of period.

[49] Schwennesen, A. T., op. cit., pp. 30–35.

[50] Information from the files of the New Mexico Bureau of Mines and Mineral Resources.
[51] Schwennesen, A. T., op. cit., pp. 138–141.
[52] Knechtel, M. M., Geologic relations of the Gila conglomerate in southeastern Arizona: Am. Jour. Sci., 5th ser., vol. 31, pp. 81–92, 1936.

and Santa Rita districts. The other is that in each of the three areas the igneous sequence began with basaltic effusion, then continued with the intrusion of intermediate or silicic rocks with which the ore deposits are associated, and ended with further effusive activity accompanied by its own phases of mineralization. That is the story offered by Butler [53] as a continent-wide generalization, and the region of southwestern New Mexico would thus appear to support the application of Butler's concept to a part of the continent where the igneous cycles seem less distinct than elsewhere.[54]

GEOLOGIC STRUCTURE

The Little Hatchet Mountains constitute a geologic unit perhaps unusually complete within itself, but many of the local relations there seen invite a consideration of broader regional relations. Among the regional problems involved three are outstanding: (1) The geosyncline that permitted deposition of a pile of rocks of Trinity age 4 miles or more thick; (2) the origin of the Little Hatchet Mountains as a member of the Basin and Range province; and (3) the structural relation between the Little and Big Hatchet Mountains. These problems are discussed at the end of this chapter after the internal features of the range have been considered.

INTERNAL FEATURES OF THE LITTLE HATCHET MOUNTAINS

Perhaps the most striking element of the geologic map and sections (pls. 1 and 2) is the presence of essentially the same sequence of sedimentary rocks in both the north and south parts of the range, the formations having been duplicated by the S-shaped Copper Dick fault shown just south of the Grant-Hidalgo county line. This fault is the dominant structural feature of the Little Hatchet Mountains, and its interpretation is fundamental to an appraisal of the ore-bearing possibilities of the range, for it is upon the restoration of the two sides of the fault to their original relative positions that the most significant conclusions are based.

In addition to the Copper Dick fault, the structural features of the range include folds, other faults, vein fissures, and features related to the stocks and their emplacement. (See pl. 12.) Nearly all structures—folds, faults, and intrusive axes, including most of the dike trends—strike westward or northwestward across the northward trend of the range itself.

The ore-bearing fissures are considered in the section on ore deposits, but all other structural features are discussed in the present section.

FOLDS

AGE OF FOLDING

The rocks of the Little Hatchet Mountains are deformed into three main folds: (1) The Vista anticline at the north end of the range, with its southwest limb, broken by the Miss Pickle fault, dipping into (2) the Howells Wells syncline; and (3) the monocline south of the Copper Dick fault. It is supposed that the monocline is the south limb of an anticline that was companion to the Howells Wells syncline prior to the formation of the Copper Dick fault.

Four stages of folding can be recognized in the development of these broad folds and the subordinate warps upon their flanks. The first stage is vague. It took place some time before emplacement of the diorite sills and may be presumed to be the earliest expression of the Laramide orogeny. The evidence for it consists of some prediorite bedding-plane faults near Old Hachita. (See p. 45.) The shape of the diorite sill in sec. 26 of the Eureka area and its position at the crest of an anticline suggest a phaccolithic body, also implying prediorite folding, but not much reliance is placed on this suggestion because of the greater probability that the sill was folded, in company with other sills of that area, during the main stage.

The main stage of folding, to which are referred the original folding along the Vista anticline, the other two principal folds enumerated above, and at least some of their related folds, occurred in the interval between injection of the diorite sills and injection of the monzonite stocks and associated dikes. In this position in the sequence of events, the main stage corresponds to the first strong folding in the Santa Rita district,[55] and thus heightens the similarity in the geologic history of the two areas. (See p. 38.)

The large diorite sill at the nose of the Vista anticline near the Ringbone Ranch and the repeated diorite outcrops in the complexly folded area on the southwest limb (see p. 42) indicate folding of the diorite, and many monzonite porphyry dikes that cross the fold lines of the Vista area prove that this folding cannot be due to the postmonzonite Tertiary stage listed below. Igneous rocks can be injected concordantly into deformed sediments and so counterfeit folded sills, as is true of the felsite and latite sills in the Little Hatchet Mountains, but the evidence here seems to favor folding of the diorite. Plastic flowage of sediments around the nose of the sill in sec. 26 (see p. 40) is in accord with this view. The absence of any indication of differential movement between stocks and sediments and the fact that parts of the Sylvanite stock transect fold axes (see pl. 12) are additional evidence of the premonzonite age of the folds. Corroborative evidence of a post-diorite premonzonite age is the fact that locally the ore-bearing solutions derived from the monzonite seem to have been directed along bedding-plane faults related to pre-existing flexures that involve diorite. (See pp. 45, 76.)

A third stage of folding occurred when some of the formations were dragged against the Copper Dick fault, modifying the south flank of the original Howells Wells syncline. Possibly to this stage could be referred also some of the subordinate folds in the general block of the Howells Wells syncline, for conceivably they could have been formed by the nutcracker action of the Miss Pickle and Copper Dick faults. A fourth stage deformed the Miocene (?) volcanic rocks and amplified some of the earlier folds in the underlying rocks.

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[53] Butler, B. S., Ore deposits of the United States in their relation to geologic cycles; Econ. Geology, vol. 28, pp. 301-328, 1933.
[54] Idem.

[55] Spencer, A. C., and Paige, Sidney, Geology of the Santa Rita mining area, N. Mex.: U. S. Geol. Survey Bull. 859, p. 63, 1935.

VISTA ANTICLINE AND ASSOCIATED FOLDS

For purposes of description the dividing line between the Vista anticline and the Howells Wells syncline along their common flank is taken at the Miss Pickle fault. The axis of the Vista anticline trends northwestward across the dissected pediment south of Vista siding. Most of that area is underlain by alluvium, but enough bedrock is exposed to permit locating a good part of the axial line reasonably well. To the northwest, however, beyond the main cluster of bedrock exposures, the isolated croppings of Cretaceous rocks and the lack of precise knowledge of the effect of the post-Miocene (?) faults prevent even a good guess as to the position of much of the axis in that direction, though it must lie southwest of the Miocene (?) rocks, which form part of the northeast limb.

The nose of the anticline is exposed near the Ringbone Ranch, where the Ringbone shale and a diorite sill in it swing northward around the Broken Jug limestone, and the dips there indicate a northwestward pitch of at least 35°. South of the nose and about half a mile from the axial line, the southwest limb of the anticline flattens out abruptly to form a broad bench a mile or so across, and the thin layer of Ringbone shale between the Broken Jug limestone and the Hidalgo volcanics is so squeezed along the bench into many small folds that outcrops of individual beds are repeated many times. (See sec. G-G′, pl. 2.) The bench narrows to the southeast as it bends into a local syncline and parallel anticline that pitch southwestward diagonally down the regional dip. The axis of the local anticline passes through the outcrop of one of the diorite sills, and near the nose of the sill the basal conglomerate of the Ringbone shale shows plastic flow of the limestone parts around the boulders of sandstone and early conglomerate. Farther east, in sec. 31, some beds of the Broken Jug limestone are squeezed into small closed folds.

Mention has been made of the effect of post-Miocene (?) folding upon the earlier folds in the underlying rocks. The Vista anticline apparently owes its present anticlinal structure largely to that stage, because when the Cretaceous beds are lifted back by the amount of the post-Miocene (?) tilting (see p. 41), the Vista anticline becomes hardly more than a bench on the flank of the Howells Wells syncline.

HOWELLS WELLS SYNCLINE AND ASSOCIATED FOLDS

The axis of the Howells Wells syncline curves from Howells Wells westward to the overlap of the Miocene (?) volcanic rocks near Livermore Spring, marking a low pass across the range. The eastern continuation of the axis is cut off by the Howells Wells fault near the wells, and the western part is twice offset by the fault and its spurs.

The north flank of the syncline is fairly regular, with only isolated areas of local folding, but the south flank, cut off by the Copper Dick fault ¾ of a mile or so from the axial line, seems more complex. The syncline appears to pitch westward at an average of 18° to 20°, but squeezing in the keel-like trough has produced local dips that vary greatly from the average. At one place the tight squeezing in the trough has caused some tiny thrust faults to form. (See pl. 10, *C*.) The axial plane of the fold seems to dip northward. In plan, and less clearly in section, the syncline is comparatively sharp at Howells Wells, in the Corbett sandstone and massive upper part of the Howells Ridge formation, but gradually broadens towards the west in the higher formations. This is brought out more clearly if the effect of the Howells Wells fault and of the Copper Dick spurs are eliminated, as has been done in figure 5.

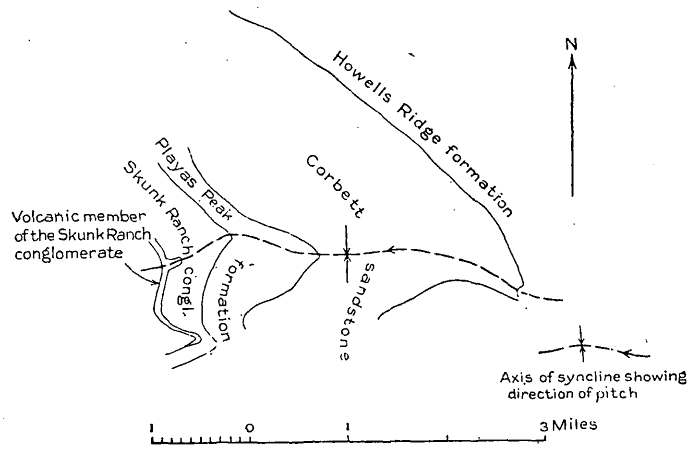
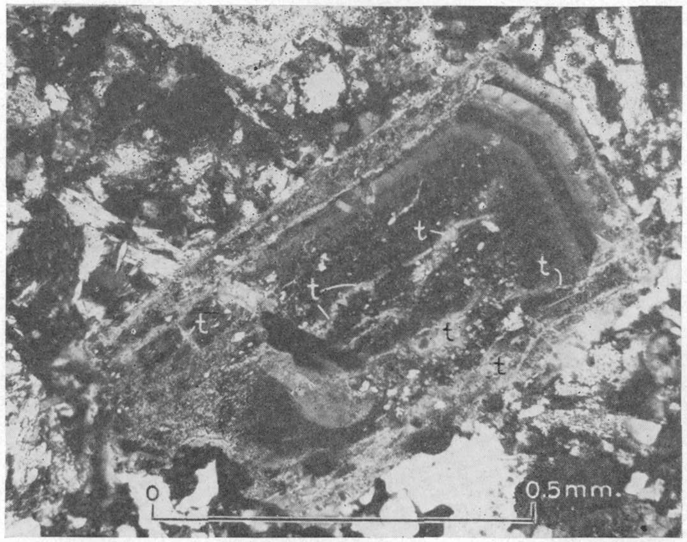
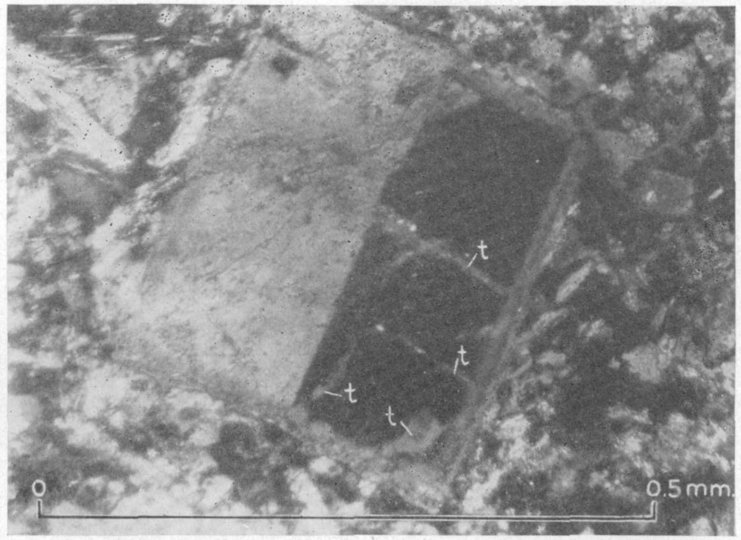


FIGURE 5.—Sketch map showing distribution of formations along the Howells Wells syncline. The effect of faults has been eliminated.

Intricate squeezing of shaly or thin-bedded parts of the formations is common at several places within the Howells Wells syncline, particularly where weak beds are caught between or under more massive and competent members. This is convincingly illustrated at the two places of local folding on the north flank of the syncline. (See pls. 1, 2, and 12.) At each of these places the massive limestone at the top of the Howells Ridge formation is folded into a smooth low anticline accompanied by an equally smooth and low syncline (pl. 10, *D*, and pl. 2, secs. F-F′ and H-H′) with considerable distortion of the thin-bedded material below. At the eastern locality so much material has been squeezed from the limbs to the crest of the anticline, and the beds so distorted, that the contact with the smoothly folded limestone caprock looks like an angular unconformity. (See pl. 11, *A*.) The amount of squeezing is indicated by the fact that a particular sandstone layer stratigraphically not more than 20 feet below the limestone on the southwest flank of the anticline is as much as 175 feet below the limestone only about 200 feet away at the crest of the fold. The structure of the beds below the massive limestone caprock at the second area is shown in section H-H′ on plate 2; the axial part of the anticline in those beds is marked by steeply pitching shallow folds, with the crinkled top of the axial zone breaking abruptly into vertical dips on either side. Equally complex squeezing is shown at the local anticline south of Howells Wells, where the shale, sandstone, and conglomerate beds of the Howells Ridge formation are squeezed between the underlying andesite and the massive limestone member at the top of the formation.



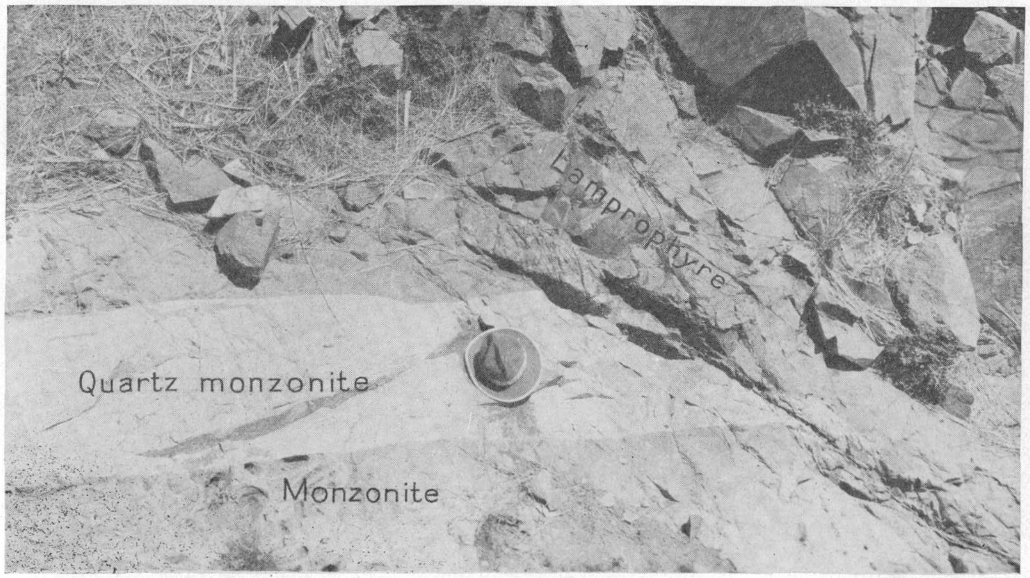
A



B

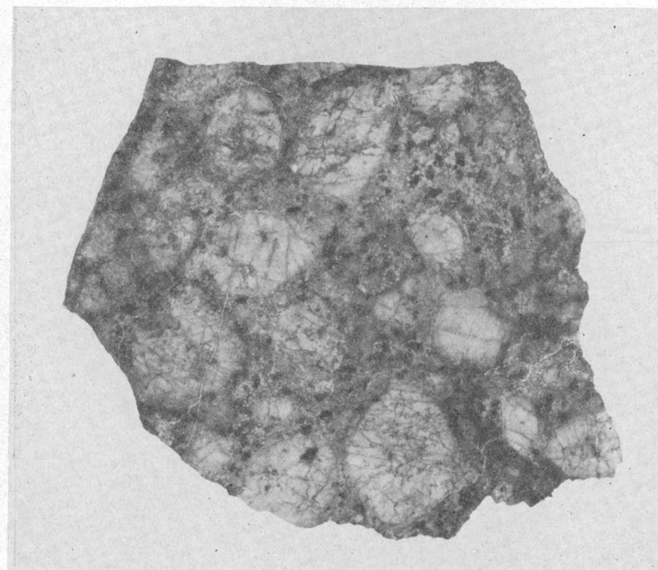
PHOTOMICROGRAPHS OF LIGHTER FACIES OF MONZONITE OF THE SYLVANITE STOCK.

Shows zoned crystals of plagioclase with threads (t) of the material of the outer zone penetrating the core of the crystal in a manner interpreted as indicating replacement. In *A*, which shows the 010 face of the crystal, the core has a composition about An_{42}. The composition of the peripheral zone ranges from An_{27} in the inner edge to about An_{20} in the outer edge, and the composition of the veinlets seems to be about An_{20}. The phenocryst in *B* is not properly oriented for exact determinations



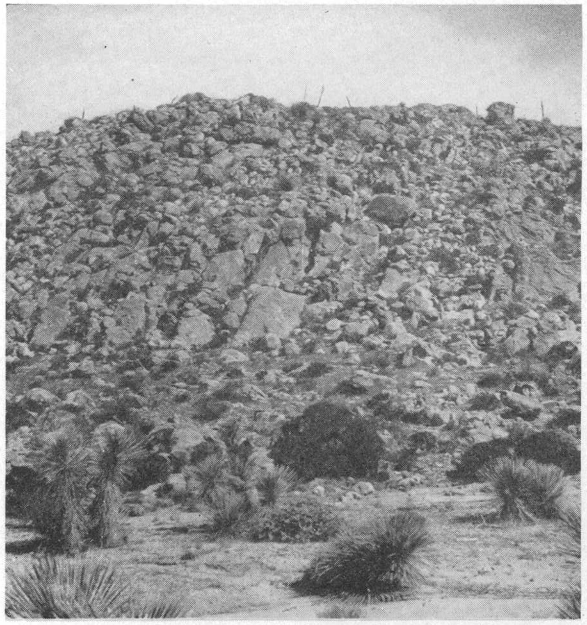
C. DIKE OF QUARTZ MONZONITE CUTTING MONZONITE AND IN TURN CUT OFF BY A DIKE OF LAMPROPHYRE.

Draw north of Sylvanite.

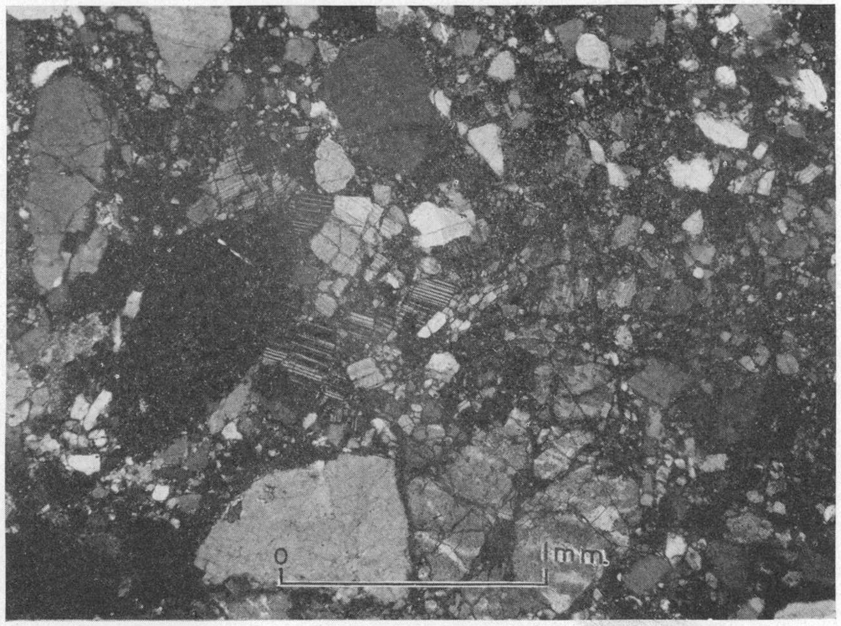


D. POLISHED SPECIMEN OF PORPHYRITIC GRANITE OF THE GRANITE PASS STOCK.

Natural size.

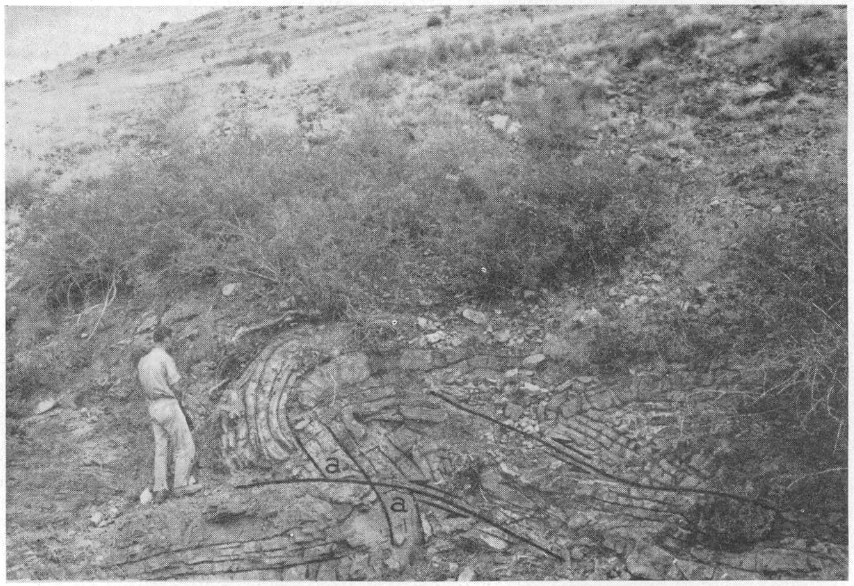


A. BOULDERY WEATHERING OF PART OF THE GRANITE AT GRANITE PASS.



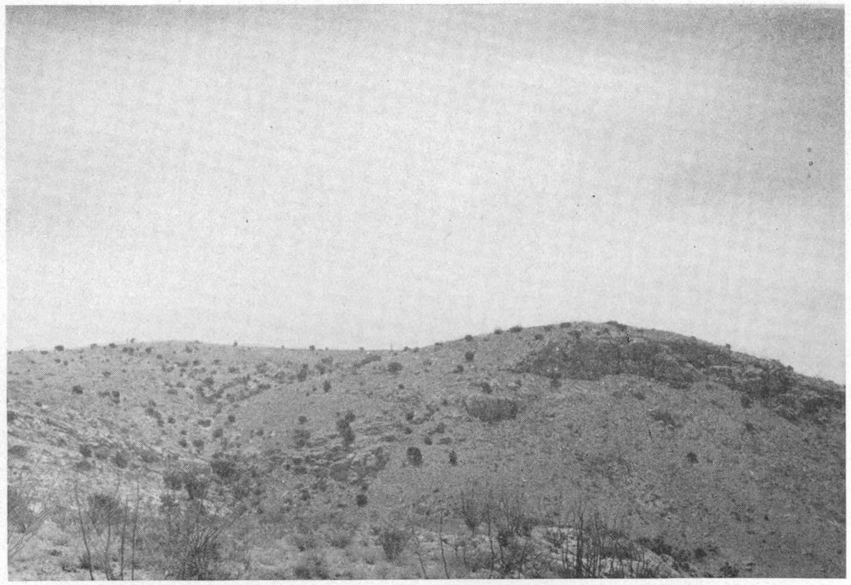
B. PHOTOMICROGRAPH OF GRANITE ALONG COPPER DICK FAULT SHOWING MICROBRECCIATION.

Crossed nicols.



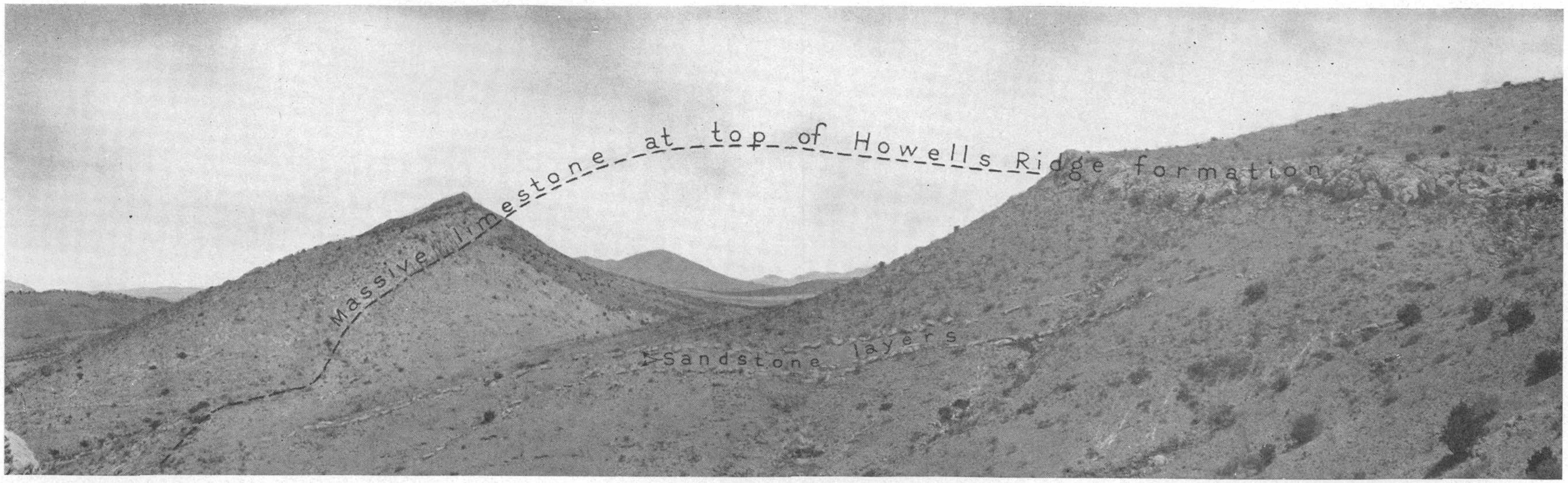
C. SMALL THRUST FAULTS IN THE CORBETT SANDSTONE.

North side of road between Howells Wells and Livermore Spring.



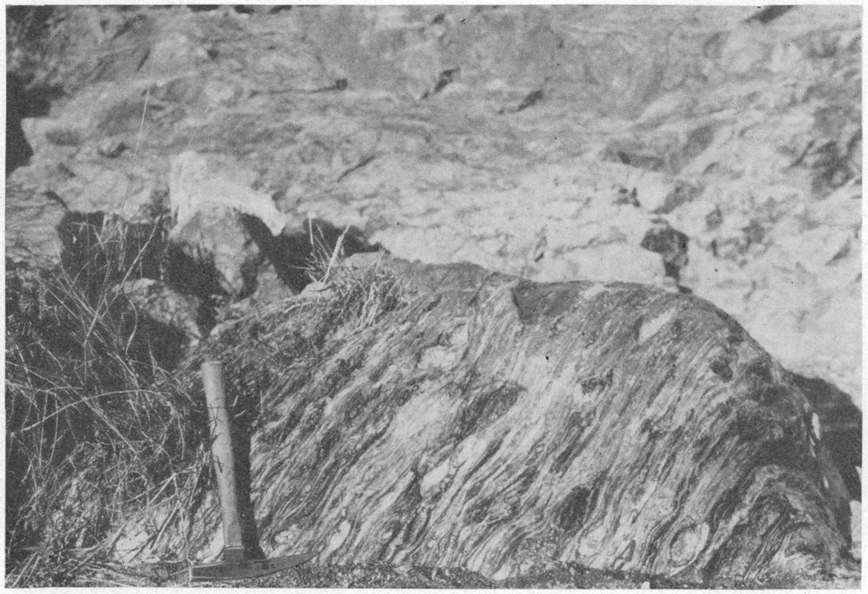
D. SMOOTH LOW FOLDS IN THE MASSIVE LIMESTONE AT THE TOP OF THE HOWELLS RIDGE FORMATION.

Sec. 11, T. 28 S., R. 16 W., on north flank of the Howells Wells syncline.



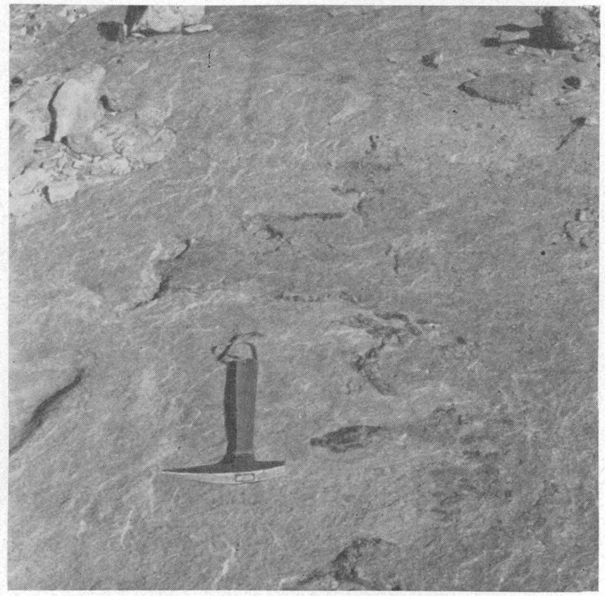
A. APPARENT ANGULAR UNCONFORMITY BETWEEN MASSIVE LIMESTONE AT TOP OF THE HOWELLS RIDGE FORMATION AND THE UNDERLYING THIN-BEDDED MATERIAL.

Counterfeited by the squeezing of the thin-bedded material from the limbs to the crest of one of the minor anticlines on the north flank of the Howells Wells syncline. View northward from point east of old stage road in sec. 11 T. 28 S., R. 16 W.



B. PLASTIC FLOW IN LIMESTONE CONGLOMERATE OF HOWELLS RIDGE FORMATION.

Bed of Sylvanite arroyo a quarter of a mile below Sylvanite camp.



C. FLOWED MARBLE OF PLAYAS PEAK FORMATION SHOWING DISTORTED STREAK OF CHERT.

Southwest of the Corbett ranch. The chert marks the contact between the white marble on one side and dark partly marmorized limestone on the other.

MONOCLINAL BLOCK SOUTH OF THE COPPER DICK FAULT

The strata south of the Copper Dick fault dip generally southwest at moderate to steep angles, 45° to 70°, in monoclinal fashion, but in the east central and south half of this block the dips swing southward sharply enough to warrant indicating the change on the map as an anticlinal axis. All other variations in strike and dip are local only and less pronounced, except, apparently, for the sharp anticline and its companion syncline disclosed by the inclusions in the monzonite in the vicinity of the Bader mines south of Livermore Spring.

The present relation of this monoclinal block to the Howells Wells syncline suggests that it was the south limb of an anticline adjacent to the Howells Wells syncline before the folds were torn apart by the Copper Dick fault. This suggestion is strengthened by the anticlinal swing of the Broken Jug strata next the Copper Dick fault—the swing is opposite to that expected if due to fault drag—and appears to be further borne out by the structure obtained when the formations each side of the fault are restored to their original position. (See pl. 13.)

DRAG FOLDING AGAINST THE COPPER DICK FAULT

Though it is not possible entirely to differentiate drag folding from other features of folding as now exposed, some dragging of the formations against the Copper Dick fault seems clearly demonstrated.

Long streamers of limestone of the Howells Ridge and Playas Peak formations have been pulled out along the fault like so much taffy. The streamer of limestone of the top member of the Howells Ridge formation north of the Copper Dick mine has been stretched out for fully half a mile, and the plastic taffylike flowage of the rock is striking. The long sliver of limestone of the Playas Peak formation southwest of Livermore Spring shows similar plastic flowage for most of its mile-long exposure. The parallelism between formations and fault in that vicinity, and local parallelism in attitude between the Lower Cretaceous and Miocene (?) rocks, strongly suggest that the south limb of the Howells Wells syncline owes some of its present attitude to drag against the fault. The amount of drag during the post-Miocene (?) stage of movement along the fault is indicated by the change in the attitude of the Miocene (?) volcanic rocks from a general dip of about 10°W. to a dip near the fault of 30°-35° NW.

Folded veins and dikes in the Santa Maria tunnel, 150 to 250 feet in the footwall of the fault, and at the Silver Trail tunnel about 50 feet in the footwall (see mine descriptions), are a further indication of drag against the fault.

FOLDING OF THE MIOCENE (?) VOLCANIC ROCKS

Two areas of Miocene (?) volcanic rocks have been described, one fringing the range on the north and the other lying west of Livermore Spring and the Skunk Ranch. In the second area, although there are several variations from a common dip, some of them due to fault drag (see above), the Miocene (?) volcanic rocks for the most part dip westward at a small angle. In the largest exposure the general dip seems to be 10° W., and in the next largest it ranges from horizontal to 17° W.

In the volcanic area at the north end of the range the Miocene (?) rocks form part of the northeast flank of the Vista anticline and dip variably northeastward at about 20° to 70°. The steeper dips are commonly near the base of the formation, flattening in the upper layers away from the anticlinal axis. A similar flattening and perhaps reversal of dip must have occurred toward the southwest in order for these rocks to have been once continuous with the Miocene (?) rocks in the Skunk Ranch-Livermore Spring area. There is no way of telling from the evidence at present available whether the Miocene (?) rocks formed a distinct anticline along the Vista axis, but they did at least form a distinct northeastward-dipping monocline that extended northwestward beyond the area mapped. The effect upon the older Vista anticline, in the Lower Cretaceous rocks, of flattening this monocline to its original horizontal position has been indicated in the description of the Vista anticline.

FAULTS

GENERAL PRINCIPLES

The terms throw and net slip are repeatedly used in this report in describing and discussing the faults of the Little Hatchet Mountains. The term throw is widely known, even though its limitations are not always kept in mind, but the term net slip is rarely used. This is not because of any lack of acceptance of the term, which is thoroughly established,[56] but because determination of the net slip is so rarely possible. Fortunately it has been possible to estimate the net slip for some of the faults of the Little Hatchet Mountains, as well as other elements of fault movement not commonly obtainable, and in order to facilitate an understanding of the discussions below, a diagram illustrating the usage of the terms is included here. This diagram (fig. 6) repre-

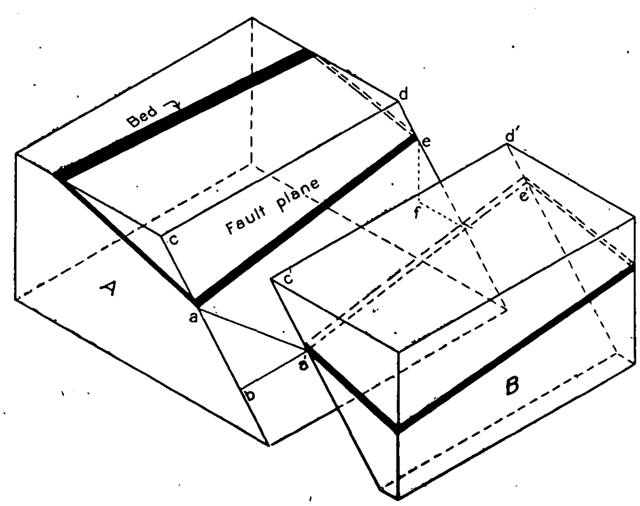


FIGURE 6.—Diagram illustrating some terms used in describing faults: *aa'*, net slip; *ab*, dip slip or dip-slip component; *ba'*, strike slip or strike-slip component; *ef*, throw.

[56] Reid, H. F., Davis, W. M., Lawson, A. C., and Ransome, F. L., Report of the committee on the nomenclature of faults: Geol. Soc. America Bull., vol. 24, pp. 163–186, 1913.

sents a block of the earth's crust, broken into two parts, *A* and *B*, by sliding block *B* downward and to the right along an inclined fault plane, the point *a* having been moved to *a'*, *c* to *c'*, *d* to *d'* and *e* to *e'*. The significance of the terms net slip, dip slip, strike slip, and throw are indicated.

Furthermore, in light of some of the discussions to follow, it is useful also to point out here some limitations of the significance of the term throw. By definition, throw is the difference in elevation between the severed ends of a faulted formation, indicated as a bed in figure 6, as measured in a vertical plane at right angles to the strike of the fault. Under that definition, the throw of a fault may range within wide limits from place to place, remaining constant only if the formations in the two walls of the fault are precisely parallel. It is nothing more than a measure, at a particular place, of the relation among amount and direction of net slip, attitude of the fault surface, and attitude of the faulted formations. Since in nature both the fault surface and the formations are generally warped, the throw rarely bears a precise relationship to the net slip, and consequently in comparing movement from place to place along a fault or in comparing the magnitude of different faults, the measurement of throw is valuable only under special conditions.

SUMMARY OF THE FAULTS

The Little Hatchet Mountains contain five major faults. They are, in order of magnitude, (1) the Hatchet Gap fault, which is either itself a thrust fault having a displacement of many miles or is related to such a fault; (2) the Copper Dick fault, having a net slip of about 15,000 feet; (3) the Miss Pickle fault, having a probable maximum net slip of about 7,000 feet; (4) the National fault, having a net slip measureable probably in the low thousands; and (5) the Howells Wells fault, whose net slip is indeterminable but which has a throw ranging from 450 feet or more on one side of the fault, through zero at a hinge point, to about 1,000 feet on the other side. The distribution of these faults, as well as of the other faults extensive enough to be mapped on the scale used, is indicated on plates 1, 5, and 12.

Five separate stages or episodes of faulting can be recognized, extending from preintrusion to post-Miocene (?) times. The first, or preintrusion stage, is represented by the initial movement along the bedding-plane faults north of the National fault at Old Hachita. The second recognizable stage occurred after the stocks were emplaced and the encasing rocks metamorphosed. Most of the ore deposits were formed in the fissures of that stage. Indications of a sharp recurrence of faulting near the close of the period of vein formation has been noted at the King-400 mine at Old Hachita, where the vein is offset by transverse faults that are themselves partly filled with the final products of deposition. Faulting again took place at some indeterminate time after the vein-forming epoch, at some places along and elsewhere displacing earlier planes of movement, and a still later stage occurred after the Miocene (?) volcanic rocks were deposited. The greatest displacement, though not necessarily along each fault, took place during the last two stages.

The major faults enumerated above, with the exception of the Hatchet Gap fault, are described in detail in the pages immediately following. The Hatchet Gap fault is the link that connects the geology of the Little Hatchet and Big Hatchet Mountains and is described in the pages concerned with the relation between the two ranges. (See pp. 52-53.) Of the other faults, only the two bedding-plane faults at Old Hachita and some members of the National fault group are given detailed treatment, the effect of the other minor faults being obvious from the geologic map and sections.

COPPER DICK FAULT

General features.—The Copper Dick fault takes its name from the Copper Dick mine, which is 700 feet south of the fault outcrop on the steep north slope of Hachita Peak.

The fault extends westward for about 6 miles, full across the range, passing beneath the wash of Hachita Valley in one direction and beneath the wash of Playas Valley in the other. Just west of the Copper Dick mine the fault begins to bend southward and near Livermore Spring swings within a short distance through a 90° arc to pass through the spring, through the Bader camp, and past the Silver Trail prospect, where it again turns, even more abruptly than before, to resume its westward trend. The outcrop length between the two sharp bends is three-fourths of a mile or more, and the total outcrop length involved in the S-shaped curve thus formed is about 2½ miles. A long spur fraying out into several members continues westward along the course of the east limb of the fault, branching off at the initial point of bending near the Copper Dick mine as if the fault fissure had tended to maintain a general course; and a string of veins trends southward through the monzonite from the second bend as if the central limb also had tended to maintain its course. In the Santa Maria tunnel, in the footwall of the fault and 500 feet south of Livermore Spring, several post-ore faults, presumably spurs from the Copper Dick, trend northwestward toward a minor bend in that part of the Copper Dick fault, and further underground operations along the S-shaped section are likely to encounter other post-ore spurs branching off at other points of bending.[57]

The Copper Dick fault lies either at the edge of the dissected pediment described on page 8 or entirely within the pediment area (fig. 2), and consequently there is little topographic relief to assist in determining the dip. To judge from observation in several deep arroyos and in two shallow mine shafts, the dip appears to lie between 50° and 63° northward throughout the present exposure.

Displacement.—The very fact that the Copper Dick fault duplicates a sedimentary section averaging nearly 19,000 feet in thickness seems proof enough that its displacement is very large. The stratigraphic throw—the stratigraphic thickness of the formations faulted out—and the horizontal separation or offset give some quantitative idea of how much that displacement may be. For example, the

[57] Lasky, S. G., Transverse fractures as co-ordinate structures: Am. Jour. Sci., 5th ser., vol. 19, pp. 451–462, 1930. Burbank, W. S., Geology and ore deposits of the Bonanza mining district, Colo.: U. S. Geol. Survey Prof. Paper 169, pp. 95–97, 1932.

offset of the contact between the Howells Ridge and Corbett formations, as measured from the hanging wall side to its projected position on the footwall side, scales nearly 4 miles, and the offset of the Broken Jug-Howells Ridge contact seems well over 4 miles. The stratigraphic throw at the more eastern of the two points on plate 12 where the estimated amount and direction of the net slip are indicated, includes 2,400 feet of the Broken Jug limestone, nearly the full thickness of the Howells Ridge formation, and whatever thickness of the Hidalgo volcanics that lies between them, and thus totals 7,000 feet or more. At the more western of the two points it includes the full thickness of the Playas Peak, Corbett, and Howells Ridge formations, and possibly a little of the Broken Jug limestone, and totals at least 9,000 feet.

The geometry of the Copper Dick fault is such that the stratigraphic throw is necessarily less than the actual or net slip, but some approximation of the net slip may be obtained by plotting the formations of the two walls of the fault surface and matching them. Obviously figures so obtained cannot be exact, but they should indicate the proper order of magnitude. The net slip thus obtained amounts to 15,200 feet near the east side of the range in the direction and inclination shown on plate 12, with strike and dip components of 7,600 feet and 13,100 feet, respectively. Near the west side of the range, at the point shown on the map, the net slip thus obtained amounts to 16,200 feet, the strike-slip component to 4,600 feet, and the dip-slip component to 15,900 feet. In round numbers, then, the net slip of the Copper Dick fault may be taken as about 15,000 feet, the strike-slip component as about 5,000 or 6,000 feet, and the dip-slip component as perhaps 14,000 feet.

Origin of the warped fault surface.—Warped fault surfaces are common, but unless caused by later folding a double bend of the magnitude and sharpness shown by the Copper Dick fault is unusual. It will be observed from plate 1 that the Copper Dick fault in a rude way parallels the strike of the formations on the south flank of the Howells Wells syncline, bending with the beds as the syncline widens out. At casual glance that does suggest a folded fault, but that could be true only were the fault earlier than the syncline, for otherwise it could hardly have been folded a mile out of its course without the fold being expressed also in the axis and north flank of the syncline. Moreover, none of the inclusions in the monzonite show any deviation such as would be required, and it may be confidently concluded that the curved form of the fault is original.

Age.—The Copper Dick fault brings the Sylvanite stock and its metamorphic halo against the unmetamorphosed sedimentary rocks of the Eureka half of the range. More important still, it also forms a sharp north limit to the mineralized area of the Sylvanite district, the rocks on the hanging-wall side being barren as far north as the fringe of the mineralized ground around Old Hachita. Thus the major displacement was at least postmetamorphism, and it would seem to have been postmineralization as well, particularly in view of the fact that the mineralized area of the Sylvanite district roughly coincides with the monzonite and its metamorphic halo (see p. 75), and in view of the essential continuity of the metamorphic and mineralization processes. (See p. 79.) Only in the unlikely event that sufficient movement occurred between metamorphism and mineralization to bring the monzonite and its halo against unmetamorphosed rocks that belong stratigraphically thousands of feet above them, might this not be true. (See pls. 1 and 13 for the geometry of this relation and p. 77 for the extent of the metamorphic halo.) But even assuming that amount of premineral movement, the postmineral movement would still have been large; that is, the unmetamorphosed sedimentary rocks brought into contact with the monzonite would have been mineralized not only opposite the monzonite but also along the fault for some unknown distance above, and the postmineral movement would have amounted to at least the full extent of the vein thus formed. It is true that under some conditions solutions rising along a fault may mineralize the rocks and fissures in one wall only, but that possibility merits little serious consideration here.

On the other hand, part of the fault obviously was in existence at least as early as the vein-forming period, as indicated by some oxidized vein matter in a shaft a little north of Livermore Spring, by the string of veins in the monzonite beyond the south kink of the fault, and by a mineralized monzonite footwall along about half the western limb of the fault. The long spur of the east limb displaces the Miocene (?) volcanic rocks and so proves that some movement was post-Miocene (?). Actually an appreciable part of the displacement may have occurred at that time, for the Miocene (?) rocks are strongly involved in the drag against the fault.

MISS PICKLE FAULT

The Miss Pickle fault receives its name from the Miss Pickle mine, which lies within the fault zone. It extends diagonally across the range for 6½ miles and, to judge from the scattered outcrops at the edge of Playas Valley, must continue beneath the valley fill for at least another mile and a half. Its general course is N.47°W. and its dip is 60° to 70°SW. For half the outcrop length the fault forms the contact between the Hidalgo volcanics and the Howells Ridge formation and elsewhere lies within the Howells Ridge formation. Except for a few gulleys along the fault line in the vicinity of hill 5654, the Miss Pickle fault has almost no surface expression.

A little mineralization is associated with the Miss Pickle fault (pl. 12), and so, like the Copper Dick fault, the Miss Pickle originated before the mineralization epoch. It likewise has postmineral movement. The two faults strike and dip toward one another and, in view of their strength, doubtless meet at depth. The relative magnitude of the two suggests that, inasmuch as they seem to be of the same age, the Miss Pickle stops against the other and is a branch of it such as is commonly found in the hanging wall of large and comparatively flat-lying normal faults. The Copper Dick and Miss Pickle faults would thus enclose a wedge-shaped mass whose sharp edge, at the line of intersection of the two faults, pitches northwestward at 15°, and from the mechanics of the situation it seems clear that movement along the Miss Pickle fault would have been parallel to that line, as recorded on plate 12.

Unfortunately, no horizon marker is exposed to permit direct measurement of the amount of movement, but by making certain assumptions some idea can be obtained indirectly. If the relation between the Miss Pickle and Copper Dick faults as just described is true, then the footwall block of the Miss Pickle fault forms the hanging wall of the Copper Dick fault north of (below) the Miss Pickle-Copper Dick wedge and must have partaken, in some degree, of the longitudinal movement along the Copper Dick fault. Thus the movement along the Miss Pickle fault would have to be less than the component along the Copper Dick in a parallel direction. On the basis of the figures estimated for the Copper Dick movement, that component would be about 6,000 or 7,000 feet, which, according to this reasoning, would then be the probable maximum net slip of the Miss Pickle fault.

West of its junction with the National fault (pl. 12), the displacement along the Miss Pickle fault would be partly compensated by the displacement of the National.

HOWELLS WELLS FAULT

The Howells Wells fault can be traced from the overlap of the fill of Hachita Valley westward past Howells Wells for nearly 5 miles, splitting into several members about 2 miles west of the wells and then dying out. It is roughly parallel to the long east limb of the Copper Dick fault and is 2,000 to 3,500 feet to the north; it lies near and along the trough of the Howells Wells syncline, whose axis is broken by some of the fault members.

Near Howells Wells, where the fault brings the top of the Howells Ridge formation against the volcanic rocks 1,100 feet below the top, the dip of the fault is 60° N. and the throw is about 1,000 feet on the north; but near the west end of the fault, where the Miocene (?) volcanic rocks are brought in contact with the Skunk Ranch conglomerate, the dip seems to be near the vertical, and the throw is on the south. The point at which the throw changes from north to south lies near the bottom contact of the Playas Peak formation.

In effect, the Howells Wells fault is now a pivotal fault, but there is some chance that it may not have been so originally. There may have been two periods of movement, with throws in opposite direction. The fault presumably originated in sympathy with one of the intermediate stages of movement along the Copper Dick fault—perhaps a post-ore stage, because no sign of mineralization has been found along the Howells Wells fault—and at that time its downthrow may have been everywhere on the north side. As already described, a late stage of movement along the Copper Dick fault dragged the Miocene (?) volcanic rocks of that area, and the drag of that block, which lies between the Howells Wells and Copper Dick faults, may have been strong enough to have pulled down the south wall of the Howells Wells fault. If so, the original Howells Wells fault presumably died out near the present point of zero throw, to be later extended westward by the drag.

NATIONAL FAULT GROUP

The National fault is the strongest, most continuous, and the central member of a group of three faults that, with numerous minor members and spurs, occupy a westward-trending zone 2 miles across. (See pls. 5 and 12.) The National fault can be traced for 2¾ miles, from the alluvium of Hachita Valley westward past Old Hachita and thence southwestward on a broad curve as far as the Miss Pickle fault, which it joins near the Miss Pickle mine. In part it seems to occupy a tight zone of movement, but elsewhere the fault zone is several hundred feet across. Plate 21 shows the details of the fault zone near Old Hachita, where some mines of the Eureka district are located along it. In general the National fault dips steeply northward, apparently between 80° and 85°, but in some underground workings the dip undulates between the vertical and 70° S. Its latest movement was later than the Miocene (?) latite dikes, one of which is cut off, west of the area shown in plate 21, by the main member of the fault zone.

The National fault crosses the Broken Jug limestone, the Ringbone shale, the Hidalgo volcanics, and part of the Howells Ridge formation nearly at right angles, in contrast to the general strike trends of the other major faults. Near the mines at Old Hachita the fault brings the monzonite and its metamorphic halo on the south or footwall side against the unmetamorphosed equivalents of the same beds in the hanging wall. The offset of the main coquina horizon of the Broken Jug limestone is about 150 feet. (See pls. 5 and 21.) At the 80-foot coquina layer in the underlying Broken Jug strata, the hanging wall is offset about 650 feet to the west, but at the contact between the Howells Ridge formation and the Hidalgo volcanics the offset is between 1,000 and 1,250 feet in the opposite direction. Evidently the movement was parallel to the dip of the beds near the main coquina horizon of the Broken Jug limestone, and the opposing offsets of the formations above and below are interpreted as due to variations in their dip, as illustrated in figure 7. The hanging wall block, then, apparently moved nearly due west relative to the footwall and at about 55° from the horizontal. This agrees with the fact that the line of intersection between the National and Miss Pickle faults, which must be parallel to the direction of movement along the National fault if the formations at the fault junction are to remain snugly in contact, pitches about due west between 50° and 60°.

The net slip of the National fault in the vicinity of the mines at Old Hachita involves the eroded tip of the stock, the full thickness of the metamorphic halo that topped it, and an unknown amount of the unmetamorphosed sediments beyond the halo; no figure may be attached to this, but the total is probably measurable in the low thousands.

The Old Hachita fault, the northernmost of the three main members of the National fault group, follows the gravel-filled draw between the King and Howard veins and splits into two main branches somewhere beneath the gravel. One of these meets the King vein at the westernmost King workings (pl. 22), and the other passes through the turquoise pits at the north edge of Old Hachita; both die out a short distance to the west in the Hidalgo volcanics. The downthrown side of both branches, which dip 50° and 60° S. against the dip of the National fault, is to the south in conformity with that of the main break, whose displacement is indicated by an offset of the formations amounting to 1,500 feet. Both branches are mineralized, as also are some links between them.

The Ohio fault, the southern of the three main members of the group, cuts diagonally across the Ohio claim south of the American mine. It strikes parallel to the other two and has a dip of 56° S., as exposed in one shallow shaft. This fault forms the south limit of the exposed part of the Old Hachita stock and brings the monzonite and its intensely silicated halo against rocks in the hanging wall that are less strongly metamorphosed. The offset of the formations amounts to 800 feet at the main coquina horizon of the Broken Jug limestone and to 400 feet or less at the top of the Ringbone shale. Just east of the coquina horizon, the fault crosses a felsite dike, apparently without displacing it, and consequently could not have partaken in any great measure in the latest, or post-Miocene (?), stage of movement.

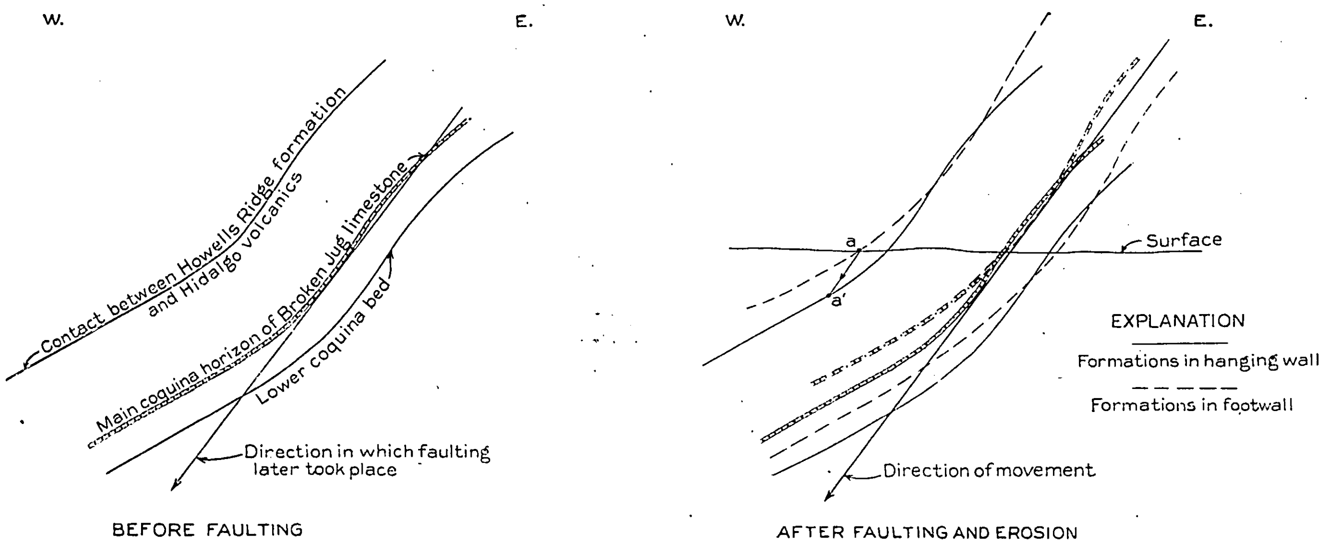


FIGURE 7.—Diagrammatic geologic sections illustrating how variations in direction of offset, as shown by the formations along the National fault, may be produced by variations in dip of the formations. Drawn to scale.

BEDDING-PLANE FAULTS OF THE EUREKA DISTRICT

A broad zone of white clay gouge, containing thin ribs of limestone and about 100 feet wide where it crosses the arroyo east of the King-400 claim, lies between the two upper diorite sills in the Broken Jug limestone north of the National fault. It can be traced from that fault northward for nearly a mile and is offset with the enclosing formations by the Old Hachita fault. (See pls. 5 and 12.) A similar zone lies between the lower of these two sills and the coquina horizon and extends from the National fault to somewhat past the Howard vein. Both apparently are zones of faulting along the bedding planes of the limestone.

The upper clay zone is crossed near the National fault by a prong of the underlying sill and seems to have been there before the sill was emplaced. Moreover, both clay zones along their course toward the north are repeatedly crossed by veins and monzonite porphyry dikes, but neither dikes nor veins seem to be offset. Nor do the dikes seem to be sheared along the line of the bedding-plane faults or along the dike walls, indicating that there has been no general bedding-plane movement since the dikes were injected. Nevertheless, there seems to have been some slight adjustment between one of these veins, the King vein, and the upper bedding-plane fault zone, in such a way that the fault zone controlled the location of the principal ore shoot. (See p. 89.)

A second area of bedding-plane faulting lies on the line between secs. 2 and 11, 2 miles to the southwest. This fault is the locus of some high-temperature mineralization that throws light on the regional distribution of the ore deposits. Here a diorite sill directly below the volcanic member of the Howells Ridge formation is exposed at the crest of a local anticline. The sill and the volcanic member have crept past one another along the flanks of the anticline, and the creep appears to have opened cracks that permitted ready penetration by mineralizing solutions rising along the Miss Pickle fault spurs.

INTERPRETATION OF ORIGINAL CONDITIONS ALONG THE COPPER DICK AND MISS PICKLE FAULTS

Several features brought out in earlier sections of the report and others to be described in later sections combine in suggesting that the Sylvanite and Old Hachita stocks may be faulted parts of the same mass. These are:

1. The entire sedimentary section of the Little Hatchet Mountains has been duplicated by the Copper Dick fault, so that essentially the same sedimentary sequence now crops out in the south part of the range as in the north part.
2. Each of the fault blocks contains a center of mineralization—the Eureka district at Old Hachita in the north block and the Sylvanite district in the south block.
3. The ore deposits of each district are associated with similar intrusive bodies, namely, with the Old Hachita and Sylvanite stocks.
4. These intrusive bodies lie in the same stratigraphic position, at and near the top of the Broken Jug limestone.
5. Each intrusive is concordant in cross section with the enclosing sediments and hence may be expected to continue, for

a greater or lesser distance, along the same general horizon in which it now crops out.

6. The main stages of faulting along the Copper Dick and associated faults occurred after the stocks were emplaced and the ore deposits formed.

7. Certain features of the ore deposits of the Eureka and Sylvanite districts suggest a zonal relationship.

The validity of the suggestion that the Sylvanite and Old Hachita stocks were originally continuous can be tested by restoring the two parts of the range to the relative positions they held before faulting, as interpreted in the following paragraphs.

Section U-U′, plate 1, has been chosen at a place that will show most clearly the relations between the Sylvanite stock and the enclosing sediments. Because of the Copper Dick fault, the original northward continuation of the plane of this section now occupies the position V-V′, and similarly its continuation north of the Miss Pickle fault now occupies some such position as W-W′, the negligible effect of the Copper Dick hanging-wall spurs and of the Howells Wells fault being ignored. Geologic sections have been drawn along the lines U-U′, V-V′, and W-W′, and these when joined end to end give a section showing the geology of the range prior to faulting. That section is reproduced as part 2 of plate 13, which as a whole shows the sequence of events leading up to present conditions.

In joining the sections the question arises as to how far one is justified in projecting the igneous masses beyond their observed relations. As indicated in section U-U′, the Sylvanite stock splits near the present surface into three main sill-like members, and the size and distribution of the visible parts of the stock suggest that at least the central and larger member should extend, without appreciable thinning, somewhere into the block between the Copper Dick and Miss Pickle faults. For section W-W′ across the Eureka district, it is believed that the Old Hachita stock may be conservatively projected below the surface for about half its outcrop length, or for about 5,000 feet. This brings the Old Hachita stock so close to the Sylvanite stock that it would seem, on the structural evidence alone, that the two should be connected; and when to this is added the petrographic evidence of original continuity (see p. 31) and the evidence of mineralogic zoning between the Sylvanite and Eureka districts (see p. 78), then it would seem that a good reason would be needed for not doing so.

The conclusion, then, is that the Sylvanite and Eureka stocks were originally parts of a long streamer of igneous rock, sheathed by a contact metamorphic halo and a zone of mineralization, that lay at and near the top of the Broken Jug limestone for a distance of 7 miles or more. The picture is a startling one, not because of the length of the igneous mass, which is not unusual for concordant bodies, but because of the unusual economic implications. Yet the only evidence in favor of the alternative possibility that the Eureka and Sylvanite districts are separate centers of intrusion and mineralization is their present discontinuity. Moreover, that alternative must call upon the same basic idea as the other interpretation, to a greater degree and with less justification, to explain existing structural features, namely, that a cross-cutting igneous mass rising from below was more able to stream out along the bedding at a particular horizon than to cross it. Thus, in balancing the two alternatives on those structural considerations alone, it is easier to conceive of a large mass, 7,000 feet thick in what is now the Sylvanite district, readily advancing along the disconformity between the Broken Jug and Howells Ridge formations and then forcing its way into the more unified Hidalgo volcanics as it encountered the wedge of that formation (see parts 1 and 2, pl. 13), than it is to conceive of such a mass lacking the power to extend much beyond the position of the Sylvanite district while a separate mass only about one-fifth as large can rise through and across the weak horizons of the Broken Jug limestone and, more improbable still, across the Ringbone shale and its upper and lower contacts and then, for no apparent reason, adopt a sill-like attitude in the heart of the Hidalgo volcanics.

STRUCTURE OF THE STOCKS

SIZE AND SHAPE

If it should be true that the stocks at Sylvanite and Old Hachita represent separate centers of intrusion, then the shape of the two masses would be as now exposed—two sill-like bodies that at some unknown depth cut down across the formations. If, as seems more likely, the two stocks were originally continuous, then, to ignore details of outline, the known part of the combined mass originally had the shape of a recumbent steep pyramid, or to use a more homely simile, the shape of a horseshoe nail, tapering from a thickness of about 7,000 feet and a width of 4 miles or more in what is now the Sylvanite district to a thickness of about 2,500 feet and a width of 2 miles in what is now the Eureka district.

If the Sylvanite, Copper Dick–Miss Pickle, and Old Hachita fault blocks are restored to their original relative positions, so that sections U-U′, V-V′, and W-W′ (pl. 1) form a continuous plane, a line drawn from the eastern point of the Old Hachita stock to the eastern limit of the Sylvanite stock would mark the general course of the southeastern edge of the Sylvanite-Old Hachita stock as a whole. The northwestern edge would be roughly along a line extending from the western tip of the Old Hachita stock to some point southwest of the Skunk Ranch, and in plan the mass would have much the shape of an isoceles triangle whose apex lies near or north of hill 4997 near the railroad. The present position of these limits for what is now left of the mass, after faulting and erosion, is shown on plate 12.

The Granite Pass stock appears to have been similarly wedge-shaped (see p. 32) but much more stubby. As indicated on plate 1, the metamorphosed parts of the Playas Peak formation extend along the bedding for at least a mile from the granite. Prior to faulting, the Playas Peak formation in the Eureka area, at the point where cut off by the Copper Dick fault, was directly up dip from the Granite Pass stock, and the fact that not even a trace of igneous metamorphism can be found in it would seem to prove that the stock never reached within a mile of that point; in other words, the stock extended something less than 3 miles beyond the present truncated exposure.

The Sylvanite-Old Hachita and Granite Pass composite stocks probably join at some point below the surface to form a larger composite body of granites, quartz monzonite, and monzonite. The more obvious factors that determine the concordance or discordance of a given intrusive mass are the load and the structural susceptibility of the country rock.[58] As may be inferred from the almost universal sill-like attitude of the several varieties and ages of intrusive rocks in the Little Hatchet Mountains, the formations there seem to be sill takers par excellence; on the other hand, except for the Devonian Percha shale, the underlying Paleozoic formations in southern New Mexico are in general more massive rocks and hence more likely to resist concordant penetration. Accordingly, the suggestion may be offered that the hypothetical Granite Pass-Sylvanite-Old Hachita stock broke across the Paleozoic and older formations and passed into long sill-like streamers only upon reaching the incompetent Lower Cretaceous formations.

Figure 8 pictures this conception. A possible modification would be that the thrust fault between the Big Hatchet and Little Hatchet Mountains (see pp. 52-53) is earlier than the granite and that the igneous rock rose along the thrust plane and then, without the necessity of changing its attitude much, formed sill-like bodies on reaching the thin-bedded Lower Cretaceous rocks in the footwall block.

DEPTH OF INTRUSION

The depth at which the stocks were intruded is roughly the depth at which the associated ore deposits were formed, and consequently some approximation is desirable. Unfortunately no close estimate of the thickness of the sedimentary cover can be made because no information is available on the precise attitude of the beds when intrusion took place, but just as certainly that thickness must have been great.

Regardless of what attitude the beds may have had, from vertical to horizontal, and regardless of how thoroughly it may be assumed that erosion had already removed any Upper Cretaceous beds and cut into the Lower Cretaceous formations, the thickness of rocks over what is now the Sylvanite stock must have been many thousands of feet. A glance at part 2 of plate 13 will show that the cover must have included at least part of the Howells Ridge formation, the full thickness of the Corbett, Playas Peak, and Skunk Ranch formations, and whatever thickness of younger beds was present, a minimum total of 10,000 feet and perhaps much more.

METHOD OF EMPLACEMENT

Geologists conceive of seven ways by which igneous bodies the size of those in the Little Hatchet Mountains may be emplaced: (1) By a lifting of the roof—the laccolithic mechanism; (2) by a settling or forcing down of the floor; (3) by forcefully pushing aside all walls; (4) by upward punching; (5) by piecemeal stoping, or the prying off and engulfing of fragments from the roof and walls; (6) by assimilation; and (7) by replacement.

Laccolithic or sill mechanism.—The first two methods, which cannot be strictly differentiated, were doubtless operative in the Little Hatchet Mountains, but they cannot have been the only methods nor the most effective, for the distribution of the stocks with respect to the enclosing formations proves that a large volume of country rock actually has disappeared. The Granite Pass stock cuts out at least the Playas Peak formation and a sliver of the Corbett sandstone, and the Sylvanite stock cuts out a major part of the Howells Ridge formation and some of the Broken Jug limestone, the several sill

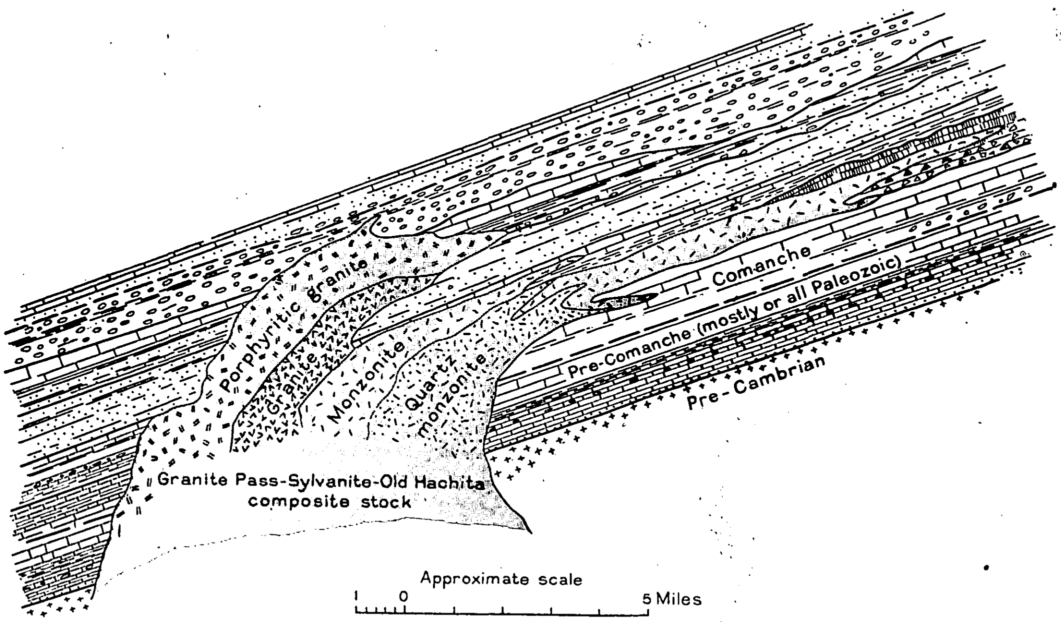


FIGURE 8.—Idealized section showing possible derivation of the sill-like intrusive bodies of the Little Hatchet Mountains as streamers from a deeper discordant mass.

[58] Cloos, Hans, Das Batholithenproblem: Fortschr. Geologie u. Paleontologie, Heft 1, 1923.

prongs having made way for themselves by some method or combination of methods other than simply elbowing aside the sediments.

Some quantitative approximation of what has happened may be obtained from a consideration of the Sylvanite stock. At the east edge of the range the Howells Ridge formation is 5,200 feet thick, including at least 300 feet of sills. Near the stock, in the vicinity of Stone Cabin Gulch, the thickness is nearly 7,000 feet, the increase being due to the presence of more sills and dikes, all too small to be shown on the map. On the other hand, the combined thickness of the ribs of Howells Ridge formation in the stock area and the slice of that formation at the roof does not exceed 2,700 feet, likewise including perhaps even a higher proportion of sliverlike sills than the border country. The size and multiplicity of these sills is shown on a geologic map of the Green mine (pl. 25) which lies in one of the ribs of the Howells Ridge formation. (See pl. 12.) In other words, the ratio of igneous to sedimentary rock is almost exactly reversed in the two areas, being about 2 to 5 along Stone Cabin Gulch and 5 to 2 in the stock area. On the basis of these figures, then, about 3,000 feet of the original thickness of the Howells Ridge formation has been effaced by the intrusion; or, stated otherwise, of the space occupied by the 5,000-foot, or greater thickness, of igneous rock now exposed within the limits of the Howells Ridge formation, about three-fifths has been obtained by obliterating the sedimentary rocks and two-fifths by crowding them aside laccolithically.

The ribs of sedimentary rock in the stock show considerable plastic flow, best illustrated by the limestone conglomerate members (pl. 11, *B, C*), and at first sight this effect suggests that some space may have been obtained by squeezing and compacting the sediments as they were crowded aside. But such flowage is common out to the very edge of the range 2 miles from the stock, indicating that the flowage is more likely related to regional forces. It is unlikely that the flowage near the edge of the range can be accounted for by an unexposed igneous body nearby; it is characteristic of the Little Hatchet Mountains that metamorphism extends parallel to the bedding for great distance from the contact, and the fact that the sediments at the edge of the range are only faintly metamorphosed would imply that the rocks are far from any major intrusion, exposed or unexposed.

Forceful pushing aside of all walls.—A general pushing aside of the walls, as a possible method of emplacement, is opposed by the absence of any peripheral schistosity such as would be expected if the stocks, acting under hydrostatic pressure, had made room for themselves in that fashion. The fluxion of the sedimentary rocks described above might be called peripheral schistosity in so far as it parallels the concordant contacts, but it is not truly so for it is persistently parallel to the bedding in the discordant parts of the contact as well.

Upward punching.—The almost universal concordance of the contacts; the distribution, thinness, and multiplicity of the sill fingers; and the generally simple continuity of the sedimentary structure in the intersill ribs with that of the country rock, all are opposed to the probability of any such aggressive mechanism as upward punching.

At only one place, along the main contact north of Stone Cabin Gulch, was evidence of forceful distortion of the rocks observed. Furthermore, the concept implies either the pushing of a plug of rock through to the surface or the compacting of the rock ahead of the igneous "punch" into a mass with wildly disordered structure. If it is true that the Sylvanite and Old Hachita stocks were originally continuous, then clearly no punching through to the surface took place, and the simplicity of the enclosing structure denies that there was any such thing as headward compaction.

Piecemeal stoping.—The next alternative is piecemeal stoping. The major intrusive masses lie within the Playas Peak and Howells Ridge formations. Both are thin-bedded formations that should lend themselves readily to the process, and the many thin sills that penetrate the sediments around the Sylvanite stock would seem to be ideal levers for prying off slabs of rock. Yet if piecemeal stoping had been dominant, the floors of the stocks should be crowded with stoped blocks. On the contrary, such blocks are few. The isolated patches shown on the geologic map represent all the blocks observed in the course of mapping, and some of these could not be mapped without exaggeration. They could be either stoped blocks or truncated tips of pendants; but if the former they were not carried far from place, for the sedimentary structure wherever observable is parallel to that of the country rock. Many small inclusions measurable generally only in inches can be found in the border zones of the Sylvanite stock, some with distinct and others with vague outlines, but not in the great number expected.

The probability of effective stoping cannot be thus arbitrarily discarded, however, because the absence of stoped blocks could be explained by assimilation. The vague outlines of some of the inclusions do suggest that process. Moreover, it seems probable that stoping in conjunction with assimilation or replacement was an important process in the emplacement of the quartz monzonite of the Sylvanite stock, as explained below. The discussion is thus led to a consideration of the two final alternatives, assimilation and replacement.

Assimilation and replacement.—With the laccolithic and sill mechanisms not the only nor most effective methods used, with both upward punching and hydrostatic forcing aside of the walls practically disproved, and with piecemeal stoping without the help of assimilation also disproved, it must be concluded that assimilation or replacement, one or both, were important processes. But the conclusion rests upon more solid ground than that, for field evidence proves that both processes were active. The two are considered together because under some circumstances it may be difficult to separate them; it would be hard to decide, for example, just where reaction with emanations from the magma (replacement) stopped and where reaction between a stoped block of partly replaced material and the magma itself (assimilation) began.

Two places are shown on plates 1 and 12 where replacement of the Howells Ridge formation by monzonite is so convincingly illustrated and so widespread that it was feasible to map the general area of hybrid rock. Both places are at the roof of the stock. Similar areas were noted elsewhere, particularly in Sylvanite arroyo, but were too small to be mapped. The details of the evidence and the description of the hybrid rock are given in the section on metamorphism. (See p. 58.)

It is obviously impossible to estimate how much of what has been mapped as monzonite is actually replaced sedimentary rock. It may be significant that hybrid rock has been recognized only adjacent to the Howells Ridge formation and that there are two facies of monzonite, one a light-colored rock where apparently intruded into the Broken Jug limestone, and the other a dark and more dioritic rock where apparently intruded into the Howells Ridge formation.

Equally positive evidence of igneous replacement, though much less widespread, has been found at the roof contact of the Granite Pass stock, where the porphyritic granite has replaced the quartzite of the formation mapped as "Quartzite and limestone of uncertain age." The details of this evidence also are given in the section on metamorphism.

Evidence of assimilation apparently in conjunction with stoping is common around the borders of the quartz monzonite phase of the Sylvanite stock, and similar effects that may be related to unexposed bodies of quartz monzonite have been observed in the monzonite some distance away. The border zones show not only "arrested stoping" by means of connecting fingers of quartz monzonite in the monzonite but also impregnation of the monzonite by feldspar and biotite for as much as 200 feet from the contact. (See p. 59.)

Conclusions.—Apparently it must be concluded, at least for the Sylvanite stock, that the monzonite made way for itself by a combination of stoping, assimilation, replacement, and laccolithic or sill-like injection. Emplacement is conceived to have taken place by the penetration of parallel sills that pushed the beds apart laccolithically, at the same time prying off the thin-bedded sedimentary rock in slabs that were assimilated before settling to the floor or being caught in the solidifying mass. The replacement of sedimentary rock by igneous material was probably an important factor in this operation, for the assimilation of stoped blocks of partly replaced rock would involve a comparatively slight further change. Most of the energy-consuming part of the work already would have been accomplished by the replacement process, and hardly more than the mechanical strewing about of minerals with which the magma was already in equilibrium would be required. The quartz monzonite facies was later emplaced by stoping and assimilation, apparently assisted by advance conversion of the monzonite into quartz monzonite material.

Conclusions regarding emplacement of the Granite Pass stock are less detailed. Granitization of the sediments was a factor, but there is some uncertainty about its quantitative sufficiency. Sill tongues of granite in the quartzite at the roof and dikes and sills in the floor suggest that stoping may have been active.

REGIONAL STRUCTURAL RELATIONS

THE LOWER CRETACEOUS GEOSYNCLINE

The great thickness of Lower Cretaceous rocks in the Little Hatchet Mountains indicates a depositional basin of geosynclinal dimensions, and the average rate of subsidence must have been unusually rapid to have permitted deposition of that thickness essentially within Glen Rose time. The rate of erosion also must have been unusually rapid to have yielded the necessary material and to have permitted the disconformities to cut so deeply. It is noteworthy that intra-Glen Rose erosion cut into and removed Glen Rose rocks already sufficiently lithified to sustain a topography of great relief and to permit boulders to be broken off, rounded, and carried away without disintegration.

The shore line evidently was near and at times within what is now the Eureka section of the Little Hatchet Mountains, moving back and forth over a strip about 10 to perhaps 20 miles or more wide. The generally disconformable nature of the major contacts in the Eureka section as opposed to their generally conformable nature in the Sylvanite section indicates that each major retreat of the sea was accompanied by a marked rise in the north part of the basin; the basin apparently was hinged along a line somewhere between the Eureka and Sylvanite sections, the south or Sylvanite section remaining under water, except during the Hidalgo and perhaps the Ringbone intervals, while the north or Eureka section was alternately flooded and exposed to erosion. Perhaps the disconformities were in part produced by submarine erosion, but in general the average position of the southward limit of the shifting shore line was presumably near the hinge axis. While the Hidalgo volcanics were being eroded from the Sylvanite part of the basin, the shore line was evidently south of that section. Whether significant or only a coincidence, the two major structural features of the range—the Howells Wells syncline and the Copper Dick fault—lie roughly at the position of the hinge axis.

Further information on the position of the shore line is given by the conglomerate members of the several formations. The conglomerates are evidently littoral and marginal neritic deposits, derived from a cliff-bordered shore line by an encroaching sea that scattered some of the pebbles and boulders along the beach while carrying others beyond the limits of low tide. The distance to which boulders and large pebbles can be carried seaward is limited, perhaps 10 or 15 miles at most,[59] and so it may be presumed that the shore line during the conglomerate stages of deposition was somewhere within what is now the Eureka section of the range for the conglomerates of the Sylvanite section and only a few miles farther north for the conglomerates of the Eureka section. The cliffs during the Skunk Ranch interval of deposition perhaps were higher and more extensive than at other times, to judge from the great amount of boulders they supplied and from the fact that Paleozoic rocks were exposed in them; moreover,

[59] Twenhofel, W. H., Marine uncomformities, marine conglomerates, and thickness of strata: Am. Assoc. Petroleum Geologists Bull., vol. 20, pp. 677–703, 1936.

they presumably were nearby, to judge from the slabby shape of some of the boulders.

If some conglomerates were carried in by swift-moving streams, then the shore line doubtless was much closer at such times. That origin is particularly possible for the bouldery conglomerate of the Broken Jug limestone near the Ringbone Ranch and for the basal conglomerates of the Ringbone and Playas Peak formations. Some of the Skunk Ranch conglomerates also may have been carried in by streams. The fresh-water beds of the Ringbone and Playas Peak formations indicate the very margin of marine sedimentation for those periods, and part of the actual shore line of the Ringbone basin is exposed.

An exposure of Hidalgo volcanics resting directly upon Pennsylvanian limestone near the center of the Pyramid Mountains, in the Lordsburg quadrangle, suggests that the northernmost position of the shore in pre-Hidalgo times may have been in the 18-mile stretch between that point and the present Coyote Hills, unless, of course, some pre-Hidalgo Lower Cretaceous beds once there had been eroded. This would check the inference stated above that the shore line was less than 15 miles distant. The post-Hidalgo basin extended at least as far north as old Brokman station, 12 miles due north of Pothook siding, where the Hidalgo volcanics are overlain by massive limestone and quartzite that correspond to the Howells Ridge and Corbett formations.

The entire section, exclusive of most of the volcanics, seems to belong to shallow-water and beach environments, as indicated by the general lithologic features, by the shallow-water coquina-making shells, and by the multiplicity of conglomerate members. The Corbett sandstone in particular indicates beach and marginal shallow-water conditions over a great area for a comparatively long interval. The specific significance of the conglomerates and fresh-water beds has been mentioned above. The massive and relatively pure *Orbitolina*-bearing limestones do not necessarily mean deep water, but rather clear water far enough from shore to be beyond appreciable contamination by terrigenous material; they may be reef limestones.[60]

The piling up of the Hidalgo volcanics to a thickness of 5,000 feet or more presumably was accompanied by a sinking of the crust over a broader area than the basin of sedimentary deposition. The center of volcanism seems to have been close to the inferred edge of the geosyncline basin and somewhat on the landward side, that is, north of the site of the Little Hatchet Mountains. This conclusion is suggested by the fact that the minor ejections during the Howells Ridge interval did not reach as far south as the site of the present Sylvanite district, and by the fact that some of the vents that yielded the Hidalgo volcanics have been recognized in the north half of the Lordsburg quadrangle.[61]

ORIGIN OF THE LITTLE HATCHET MOUNTAINS

The origin of the ranges of the Basin and Range Province has been a matter of debate since they were first described in 1874 by G. K. Gilbert, who suggested that they are fault blocks. Fenneman [62] has summarized the chief points supporting the fault hypothesis and states:

> If mountains are fault blocks not yet worn down, the base of the fault should be straight (or as nearly so as a fault should be). If such a straight base is found cutting across the strike of strong and weak rocks alike, the presumption is very strong that it represents a fault in its first erosion cycle.

The most direct evidence would be fault features along or parallel to the edges of the range. With the exception of a single southward-trending fault cutting the Tertiary rocks at the west-central edge of the range, there are no such features in the Little Hatchet Mountains. The range does, however, have the straight base emphasized by Fenneman, not only on its east front, but likewise on its west, particularly in the north half. Such remarkable straightness for the range in general, across the trend of the formations, is hard to explain in any way other than by faulting, though at the south tip the straight foot on the west may be due to a stripping away of sedimentary rocks from the hard granite, the contact at that place being parallel to the foot of the range.

RELATION BETWEEN THE BIG HATCHET MOUNTAINS AND LITTLE HATCHET MOUNTAINS

The Big Hatchet Mountains and Little Hatchet Mountains are separated at Hatchet Gap by a group of small isolated hills that rise out of the valley fill connecting Playas and Hachita Valleys. The geologic link between the two ranges is exposed in the southernmost of these hills, where the Paleozoic rocks of the Big Hatchet Mountains, as represented by Magdalena limestone of Pennsylvanian age, are in contact with the Granite Pass stock along a fault that strikes a few degrees north of west across the north toe of the hill. The outcrop length of the fault is about 900 feet; its dip, as nearly as can be told from the topographic expression of such a short exposure and from some shallow cuts dug across it, is about 60° south under the Magdalena limestone. This is the Hatchet Gap fault.

The stratigraphic throw of the Hatchet Gap fault involves the full thickness of the Lower Cretaceous sediments and concordant late Cretaceous or early Tertiary stocks exposed in the Sylvanite half of the Little Hatchet Mountains, 23,000 feet or more; all but a few hundred feet of the basal part of the Magdalena limestone, or about 2,000 feet;[63] and whatever Triassic, Jurassic, and pre-Broken Jug Cretaceous beds may be present. The total is about 25,000 feet or more, a figure so large as to imply that the Hatchet Gap fault is either a thrust fault or related to a thrust fault that brings the rocks of the Big Hatchet Mountains over those of the Little Hatchets. Figure 9 shows four possibilities: (1) That the Hatchet Gap fault is the thrust fault itself; (2) that it is a tear fault limiting the overthrust block on the side; (3) that it is a minor fault offsetting the thrust plane and only counterfeiting a fault of major throw; and (4), a modification of (3),

[60] Lasky, S. G., A newly discovered section of Trinity age in southwestern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 22, p. 540, 1938.
[61] Lasky, S. G., Geology and ore deposits of the Lordsburg mining district, Hidalgo County, N. Mex.: U. S. Geol. Survey Bull. 885, pp. 13–14, 1938.
[62] Fenneman, N. M., Physiography of Western United States, pp. 333-340, 1931.
[63] Darton, N. H., "Red beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 346, 1928.

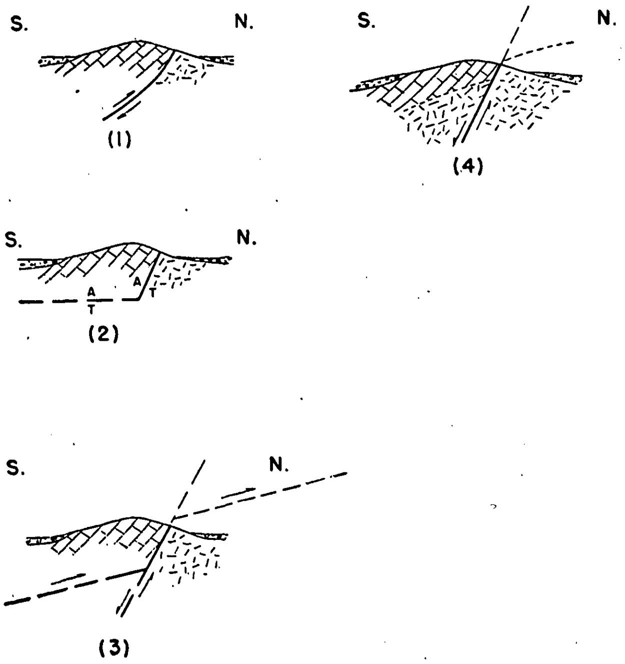


FIGURE 9.—Hypothetical sections across the Hatchet Gap fault.

that the thrust plane was healed by the granite and that the Hatchet Gap fault is a minor fault of later age. (See p. 47.)

The implication that the Hatchet Gap fault is related to thrust faulting is confirmed by reconnaissance observations at the south end of the Big Hatchet Mountains, where a northwestward-trending syncline of rocks containing Lower Cretaceous (Trinity) fossils has been shoved against the northeastward-dipping Magdalena limestone of the main part of the range. An overturned U-shaped anticline wraps around the north end of the syncline. These observations are recorded on plate 14, which is compiled from Darton's map [64] and sections with additions of my own. Shortly after these observations were made, R. T. Walker, then of the United States Smelting, Refining, & Mining Co., was reported to have discovered evidence of thrust faulting in the Sierra Rica on the east side of Hachita Valley, and later this was corroborated during a short visit by J. B. Reeside, James Gilluly, and me when we found that some of the hills on the north side of the Sierra Rica are composed of Carboniferous limestone overlying Cretaceous sandstone and shale. The exact relation of the structure in the Sierra Rica and at the south end of the Big Hatchet Mountains to the Hatchet Gap fault cannot yet be given because of the isolated nature of the observations, but it seems safe to conclude that the Big Hatchet Mountains are part of a plate thrust against the younger rocks of the Little Hatchet Mountains. The age of this thrusting would be post-Trinity and pre-Miocene (?), because the steeply dipping beds on the southwest flank of the syncline described above are overlain by conglomerate that constitutes the basal part of the subhorizontal Tertiary (Miocene?) volcanic rocks of that area.

[64] Darton, N. H., Geologic map of New Mexico: U. S. Geol. Survey, 1928. Scale, 1:500,000. Darton, N. H., "Red beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 346, 1928.

INTERPRETATION OF GEOLOGIC HISTORY

The rocks of the Little Hatchet Mountains doubtless rest upon a foundation of Paleozoic rocks, but the observable historical record begins in late Trinity time when the site of the Little Hatchet Mountains lay beneath an encroaching Comanche sea. The shore line seems to have been only a few miles north and west of the present north edge of the range and was marked by wave-cut cliffs of Paleozoic and perhaps earlier Lower Cretaceous rocks that yielded the conglomerate parts of the Broken Jug formation. At intervals the debris received by the water was predominantly sandy, and at least a little clay was received most of the time. Oyster beds were present offshore, and at times the water became sufficiently clear for deposition of massively bedded *Orbitolina*-bearing limestones. Subsequently at least the north part of the basin of deposition was brought above sea level and was exposed to deep erosion, and a relief of more than 2,000 feet was carved into the Broken Jug limestone. As a result of this uplift, the shore line moved to the vicinity of what is now the Ringbone Ranch. A shallow arm of the sea in that area became freshened by surface waters and into it was brought the clay and sand that became compacted into the Ringbone shale. As the arm became filled, its deposits spread over the eroded surface of the Broken Jug limestone, some of whose hollows were first filled with boulders and pebbles of the earlier Lower Cretaceous rocks. Volcanic activity began during that interval, starting with preliminary explosions that yielded a little volcanic material to the shale and sand, and continuing with the extrusion of a thin flow of lava that apparently was deposited on dry land. Deposition of sedimentary material was shortly resumed, but was soon interrupted once more while a layer of coarse volcanic breccia was deposited, and considerable tuffaceous material was added with some of the clay during the next stage of sedimentary deposition, which ended sharply, long before the eroded part of the Broken Jug limestone was completely covered, with a rapid outpouring and accumulation of basaltic breccia that covered the Ringbone shale and the exposed parts of the Broken Jug limestone. Volcanic activity continued, chiefly as quiet effusion of lava, until more than 5,000 feet was deposited, being interrupted by only one short interval of sedimentary deposition.

The volcanic pile was then subjected to such active and deep erosion that it was completely removed from the part of the area now occupied by the Sylvanite section of the Little Hatchet Mountains, while a relief of over 1,200 feet was cut into the remaining part. The entire area later subsided, and the eroded surface of the volcanic rocks, as well as the Broken Jug limestone where the volcanic rocks had been removed, was covered by the sand, clay, gravel, and limestone that make up the lower part of the Howells Ridge formation. Again oyster beds were present.

Volcanic activity was temporarily resumed at one stage of the Howells Ridge interval, shortly before the massive *Orbitolina*-bearing limestone at the top of the formation was deposited. The sea retreated rapidly after the Howells Ridge interval, and the shallow-water and beach conditions that resulted were maintained over a broad area while the 4,000 feet of Corbett sandstone accumulated. Further emergence of the north part of the basin led to erosion of the Corbett sandstone and the carving of a topographic relief amounting to perhaps as much as 2,500 feet. The south part of the Little Hatchet area remained under water and the deposition there taking place eventually encroached upon the eroded part of the Corbett sandstone and covered it with the sand and gravel of fresh-water origin that now make up the lower part of the Playas Peak formation, the deeper hollows having first been filled with boulders of earlier Lower Cretaceous rocks. Then again deeper water prevailed, and in it was deposited a thick section of massive limestone identical with that at the top of the Broken Jug and Howells Ridge formations. This was later brought to the surface in the north part of the basin and was deeply eroded; then again the sea returned, this time to receive the clay and gravel of the Skunk Ranch conglomerate. The cliffs bordering the shore of this sea were at that time relatively near and were probably high and extensive, and in them must have been exposed some of the earliest members of the Lower Cretaceous rocks. Paleozoic rocks were uncovered during the latter part of the Skunk Ranch interval, and some of them were brought in to make up part of the Skunk Ranch conglomerate. The latest recorded volcanic activity of the Lower Cretaceous cycle occurred during the Skunk Ranch interval.

The sedimentary record is missing from that point on, but presumably rocks of Upper Cretaceous age eventually were deposited. Following that, in late Cretaceous or early Tertiary time, regional orogeny and intrusive igneous activity began. The precise sequence of the earliest events is a little uncertain, but apparently the sediments were first tilted an unknown amount, the diorite sills were emplaced, and then the rocks were compressed into the Howells Wells syncline and shallow anticlines on either side, the incompetent members such as the Ringbone shale being squeezed into close folds. Into these folded beds were forced the main intrusive bodies. Several pulsations occurred, and bodies of composite character were formed. They are conceived to have approached the surface through the older rocks along a common conduit and then to have spread out sill-like when the structurally susceptible beds of the Lower Cretaceous formations were reached. One of the sill-like bodies extended for at least 7 miles and become the Sylvanite-Old Hachita stock. Emplacement appears to have been in part by lifting the roof, in part by replacing the sedimentary rocks, and in part by stoping off slabs that were assimilated by the liquid igneous rock into which they dropped.

Solutions, or emanations of some sort, given off by the magma of the different stages, and perhaps even ahead of the earliest pulsation, penetrated the sediments and converted them into silicate rocks. Volatile constituents began to accumulate in the high point of the liquid mass, the tip of the Sylvanite-Old Hachita stock, while the magma was still in a mushy condition; they modified this mush and its later solidified counterpart, and the excess streamed out and metamorphosed the enclosing sediments. The solidified intrusive rocks and the enclosing sediments were cut by dikes derived from still liquid parts of the magma, and additional metamorphic alteration followed that stage of igneous activity. Cracks eventually opened in the rocks, many of them attempting to follow the dikes as simple fissures while others developed into well-defined faults, and further emanations, apparently escaping continuously, carried deposits of gold, silver, copper, lead, zinc, arsenic, and bismuth into these fissures and faults.

Some additional fault movement occurred locally during the late stages of mineral deposition, but the most effective movement or movements took place after the ore deposits were formed.

Erosion was presumably going on all that time, and more igneous rock, in the form of felsite and latite dikes and sills, managed to penetrate the older rocks at some later period after so much of the original cover had been removed that the heat brought in by the earlier igneous activity had dissipated. The felsite and latite also became mineralized, but only in a minor degree. As erosion continued, it eventually exposed these rocks as well, and upon the eroded surface of the several formations was deposited the volcanic ash and breccia that marked the beginning of the Miocene (?) volcanic period. The pyroclastic rocks were covered by lava flows, and the lavas were followed by a related stage of mineralization, though no deposits of commercial value were formed in the Little Hatchet Mountains.

Folding was resumed after the Miocene (?) lavas had been deposited and amplified some of the earlier folds, and then further faulting occurred. The major cumulative result of the several stages of faulting was the duplication of essentially the full thickness of Lower Cretaceous rocks by the Copper Dick fault, and with it a duplication of the igneous rock of the Sylvanite-Old Hachita stock in such a way as to counterfeit two separate intrusive centers, which, with their associated mineral deposits, now constitute the Eureka and Sylvanite mining districts. The Copper Dick fault apparently reached deep enough to tap the reservoir of Miocene (?) rocks and received some of the igneous material in the form of granite dikes.

There is strong probability that the Little Hatchet Mountains owe their present general outline to basin-and-range faulting along the eastern and western fronts, and, if so, the existing Copper Dick and associated faults doubtless were parts of the basin-and-range system. Erosion consequent upon the latest displacement on these faults, and controlled by the general difference in erosional susceptibility of the rocks on either side of the Copper Dick fault, has brought the range largely to its present condition. The Miocene (?) rocks have been stripped from the uplifted Sylvanite block, and the old topography of the underlying rocks has been recarved into a more youthful aspect; the great amount of resistant metamorphosed rocks has prevented erosion from proceeding rapidly and thus has preserved the relative highness of that half of the range. In the depressed block of the Eureka district, on the contrary, erosion has removed the Miocene (?) rocks from a part of the area only, and in that part the pre-lava erosion surface has in some degree been preserved. Post-lava erosion modified this surface somewhat and partly covered it with a skin of gravel, and at that time the Little Hatchet Mountains consisted of a small desert range whose north slope was the eroded scarp of the Copper Dick fault and which was bordered on the north by a group of isolated hills. A Recent rejuvenation of drainage has removed some of the gravel and partly restored the continuity of bedrock exposures among these hills and between them and the main part of the range.

IGNEOUS METAMORPHISM

SCOPE OF THE TERM

The rocks that border the Sylvanite-Old Hachita and Granite Pass composite stocks are metamorphosed for varying distances from the contact—the sedimentary material into the silicated or partly silicated rocks customarily known as "contact-metamorphic" rocks, and the old volcanic rocks in a somewhat different way.

The changes were produced through a reconstitution of the original rock-making minerals under the influence of heat and pressure and with addition of new material, both the heat and the added material being brought in by solutions migrating from the solidifying intrusive bodies. Some of these solutions altered the intrusive rocks themselves as they passed through the solidified crust on their way out. In addition, there was some conversion of sediments into what now looks like igneous rock by emanations from the magma at a stage later than some of the so-called contact-metamorphic silication, and some assimilation of country rock by the magma itself. These four processes—the "contact metamorphism" of the invaded formations, technically called exomorphism, the internal alteration of the intrusive rocks, called endomorphism, and the assimilation and replacement of country rock, partly endomorphic, partly exomorphic—are included here under the term igneous metamorphism. As already mentioned, it is sometimes difficult to differentiate fully between assimilation and replacement; consequently these two processes are considered together in this report.

The ore deposits of the range were formed by solutions of the same origin as those causing metamorphism and initially of similar composition, and strictly speaking, their formation was an integral though late part of the metamorphic process, but the ore deposits are such that for purposes of description they are best considered separately. In most mining districts of igneous affiliation the period of ore formation is either clearly a part of the main stage of igneous metamorphism or is so far removed that the concentration of the ore and associated gangue minerals into veins may consistently be considered a distinct phase of activity whose genetic relation to metamorphism must be assumed, however reasonably. In the Little Hatchet Mountains, however, even though the deposits are of the vein type and distinctly separable from the contact rocks, there seems to be a complete transition from the accumulation of a volatile residuum during a late pyrogenetic or incipient deuteric stage, through igneous metamorphism by the escaping residuum, to the formation of ore deposits. (See pages on origin of the late Cretaceous or early Tertiary deposits.) The point at which igneous metamorphism is assumed to stop and ore formation to begin must be chosen arbitrarily, and for the purpose of this report it is chosen at the period of fracturing that yielded the fissures in which the ores were deposited or along which the ore-forming solutions passed to more distant places. The distinction, then, is between widespread metamorphism and alteration and that confined to the ore deposits and their immediate walls.

CONTACT METAMORPHISM OF THE INVADED ROCKS

Contact metamorphism of the invaded rocks is noteworthy for several reasons—its typical zoning and its dependence on the structure of the invaded rocks, the great distance to which it extends in some directions, and the time relation between metamorphism and solidification of the intrusive rocks.

DISTRIBUTION

The distribution of the metamorphic rocks is shown with a distinctive pattern on the geologic map. (See pl. 1.) As illustrated there, metamorphism extends for a surprising distance from the contact in some directions, and there is a remarkable difference between the width of the halo parallel to the bedding of the formations and the width normal to the bedding. In part these features are due to the character of the rock affected and perhaps also in some degree to the character of the intrusive mass responsible, but chiefly they are due to the structure of the invaded rock and to the resulting difference in permeability in different directions. Clearly the metamorphosing emanations were able to penetrate much farther along the bedding planes than across them, a feature everywhere observable where solutions travel through sedimentary rocks.

The influence of the sedimentary structure is most clearly shown around the Sylvanite stock, whose metamorphic halo ranges from about 500 or 600 feet wide at the roof of the stock and along the floor from Hachita Peak east, as measured normal to the bedding, to more than 2 miles wide at the east side of the stock where the width is measured parallel to the bedding, silication extending under the fill of Hachita Valley along some beds. The lithologic character of the formations seems to have been a minor factor, for the narrow part of the halo at the roof of the stock is in thin-bedded shaly rocks of the Howells Ridge formation, the narrow part at the floor is in the more massive and limy beds of the Broken Jug limestone, and beds of every variety are included in the widest part of the zone. Around the Granite Pass stock the width of the metamorphic zone ranges from a few tens of feet in the Corbett sandstone to more than a mile in the Playas Peak formation, extending along some layers beneath the alluvium of Playas Valley. Differences in the lithology of the Corbett and Playas Peak formations were partly responsible for this, but structure presumably was a factor.

There is a similar difference in the width of the halo normal to the bedding and that parallel to it at Old Hachita, but that area is too cut up by erosion and by faults for the range of difference to be observed fully.

CHARACTER AND ZONING

IN THE SEDIMENTARY ROCKS

The metamorphosed silicated rocks contain a variety of metamorphic minerals whose composition and distribution depend in part on the composition of the original rock, in part upon distance from the intrusive body, and in part upon substances brought in by the metamorphosing solutions. Among these minerals are garnet, ranging in color from white to deep brown and in composition from nearly pure andradite to nearly pure grossularite; pyroxene, primarily diopside but including a sodic variety; scapolite, invariably close to Ma_{64} in composition; feldspar, including orthoclase, albite, and more calcic plagioclase; epidote, ranging from deep green pistacite to pinkish clinozoisite; actinolite and tremolite; magnetite and specularite; biotite; andalusite; muscovite; ilvaite; pyrite; chalcopyrite; wollastonite, observable in minor amounts in thin section only; and sphene. These are listed roughly in order of apparent abundance. With these new minerals there is always a variable amount of recrystallized calcite, which in places forms extensive beds of marble, and also old inert grains of quartz.

Near the intrusive body many of these new minerals form comparatively coarse-grained rocks, individual beds or parts of which consist predominantly of one or two minerals. Garnetites seem the most common, and then scapolite-diopside and diopside-albite beds. The iron oxides and chalcopyrite apparently accompany the garnet beds, but nowhere in anything approaching commercial quantities. Indeed, only here and there may they be recognized in hand specimens, yet so much magnetite is present in the arroyo sands that there must be a moderate amount of it well distributed. Interbedded with the coarse-grained beds are light-colored, tough, and close-textured rocks properly called hornstones. With increasing distance from the igneous contact the pyroxene-garnet-scapolite inner zone grades into an actinolite-tremolite zone of variable width that eventually grades into a zone of normal rocks containing only scattered amphibole crystals. The beds of marble, where present, occupy a zone intermediate between the pyroxene and amphibole zones and illustrate in a most convincing fashion the idea that tremolite and actinolite are more readily formed than a limestone can be recrystallized or than the carbonaceous matter responsible for the color can be discharged.

This zoning is one of the most apparent features of the contact zone, though there is no simple parallelism to the contact; on the contrary there may be extreme interfingering, with areas of actinolite- or tremolite-bearing beds well within the inner zone. This is illustrated, among other places, by the metamorphosed Howells Ridge strata just below Sylvanite, where diopside beds, tremolite-bearing marble, garnetites, and hornstones are closely associated, and by some of the scapolite beds in which the scapolite poikiloblasts are crowded with crystals of actinolite. One such scapolite bed is in direct contact with the monzonite. The situation is analogous to the presence of masses of limestone and shale well within the halo but entirely unmetamorphosed; presumably, such masses were never hot enough for their minerals to react at all, and in the amphibole bodies spacially out of place the temperature was not high enough to convert the amphibole into the corresponding pyroxene.

The above statements stress the influence of temperature on the distribution of the silicate zones, but another and equally important factor is the addition of new material. The effect of this factor is reflected in the inner zone by the abundance of such minerals as andradite and scapolite, which could not have been developed by a simple reconstitution of the original minerals. The amphiboles, on the contrary, may so develop, and the proof that they have done so can be found in skeletal crystals of actinolite and tremolite in the amphibole-bearing marble, in which the small amount of magnesia and silica originally present were reconstituted into amphibole until exhausted while the residual calcite was recrystallized to marble. (See pl. 15, *A*.) Thus, the amount of new material added, as well as the amount of heat, decreases with increasing distance from the intrusive body.

These several generalizations apply in different degree to the various sedimentary formations. The general character of the silicate beds at any part of the metamorphic zone varies in accordance with the original rock, as is illustrated by the silicated beds of the widely divergent Broken Jug, Ringbone, Howells Ridge, and Corbett formations. At Old Hachita most of the metamorphosed Broken Jug limestone belongs to the inner zone and consists of massive garnetite, albite-diopside, and scapolite-diopside beds, accompanied, at the south tip of the stock and chiefly south of the Ohio fault, by considerable marble. All these silicated rocks, except some of the garnet beds, are light or cream-colored and weather so as to resemble the small outcrop of monzonite at the core, but on short acquaintance the scapolite beds may be readily identified because of the way the clusters of scapolite weather out in small knots, and the albite beds may be identified because of their whiteness. The scapolite rocks have been used for building stone locally. The original sandy beds of this section can be identified readily because the quartz grains and sandy and conglomeratic streaks preserve their original character in the silicated matrix. The edge of the halo is marked by the appearance of actinolite and by the fading of the actinolite part into normal-appearing limestone. The weathered surface of rock that is partly actinolitized resembles the surface of weathered sandy limestone, and the main part of the halo may extend farther along the bedding than was recognized. The variations from one kind of rock to another are illustrated by figure 13.

In the Sylvanite section the metamorphosed Broken Jug strata are in general similar to those described above. In one of the scapolite beds the scapolite porphyroblasts form tufted aggregates as much as 1¼ inches long. Beds of porcelainlike hornfels having preserved shaly fracture are common, and many of them look like white chert; some are so fine-grained even under the microscope that their full mineralogic composition remains doubtful. A thin section of a typical specimen shows in part an aggregate of quartz, feldspar (including rare grains of twinned plagioclase), and minute granules of diopside, garnet, and epidote. Much of the micrograined feldspar has low indices and, to judge from the brilliant whiteness of the rock, may be albite. The original conglomerate beds are marked by quartzite and chert knots in a silicate matrix. At one place on the contact, west of the Copper Dick mine, some prospecting has been done on chalcopyrite in a layer of andradite. The chalcopyrite seems intimately associated with the garnet and particularly with a little ilvaite, and some apple-green sodic pyroxene also is present. The occurrence seems different from the chalcopyrite deposits at the Copper Dick mine and is the only place in the range where contact-metamorphic sulfides were noted other than the scattered grains of pyrite that are everywhere present. Actinolite and tremolite show up in the otherwise unaltered limestone at the fringe of the silicated beds and follow some beds many hundreds of feet, as shown by the metamorphic pattern on the map west of the Copper Dick mine. Similar amphibolized beds crop out at the extreme east edge of the range.

In the Ringbone shale, metamorphosed only in the area west of the American mine (see pl. 20), the basal conglomerate now consists of massive garnetite with pebbles and boulders of chert and quartzite. The overlying beds, originally shale, are now white cherty rocks that retain their shaly fracture; they are spotted with epidote and cut by stringers of garnet, and a thin section discloses a microscopic and low-refringent feldspathic mosaic.

The Howells Ridge formation illustrates excellently the long distance to which silication may extend parallel to the bedding, for in about a third of the formation the silicated beds extend to and under the alluvium of Hachita Valley. Likewise, the Howells Ridge formation illustrates the metamorphic zoning better than any of the others. Most of the sedimentary band extending through the Sylvanite stock past the Little Mildred and Creeper mines (see pl. 12) now consists of garnet beds, with associated minor amounts of epidote, pyroxene, and feldspar, but in general the rocks of the Howells Ridge formation in the inner zone are gray to purple and greenish hornstones. In some of these rocks the sedimentary banding is still preserved in minute detail, but in others the hornstone is a dense structureless rock. The limits of this inner zone lie roughly about 1,000 feet from a line connecting the easternmost points of the stock. Beyond the inner zone the chief change is actinolitization of the maroon beds and marmorization of the limestone and limestone conglomerates, and the width of this outer zone at places is as much as 10 times the width of the inner zone.

One of the maroon beds may be used to illustrate the metamorphic transition. The original rock is an ordinary sandy, limy mudstone containing much iron oxide dust. Toward the contact, and at distances from it variable from bed to bed, needles of green actinolite show up in marmorized spots in the maroon rock, and a thin section discloses spongiform crystaloblasts of actinolite in a matrix of residual quartz and recrystallized calcite. This grades into rock containing compact felted aggregates of actinolite needles that are less spongiform and skeletal than in the preceding stage and have only a few percent of interstitial calcite; this rock in turn merges into a dense green to purple cherty hornstone composed of a microcrystalline intergrowth of calcite, epidote, diopside, and garnet dust. Weathering of one of the hornstonelike beds along the arroyo below Sylvanite shows it to contain exceptionally large interlacing crystals of nearly pure diopside. Brown or green biotite is present instead of actinolite in a large though subordinate part of the maroon beds, and the weathering out of the biotite pockets gives the rock a worm-eaten appearance.

The silicated rocks in the narrow halo at the roof of the stock west of Stone Cabin Gulch are chiefly the chertlike beds. The metamorphism in that area does not quite reach the limestone bed that marks the top of the Howells Ridge formation, but east of the gulch for well over a mile the limestone bed contains a moderate amount of actinolite, the actinolite parts showing up like sandy streaks.

Metamorphism of the Corbett sandstone is noteworthy for the narrowness of the zone and for the presence of andalusite, both features probably being functions of the character of the formation. So far as the naked eye can tell, the sandy shale and quartzite beds are affected for not more than 25 feet from the contact and the change seems to be only in the formation of flakes of white mica, chiefly on the parting planes. The microscope discloses, however, that considerable andalusite (chiastolite) is present, as well as biotite. This is a change that might be expected, the original sericite and chlorite of the shaly parts having presumably reacted to form biotite and andalusite. The metamorphic rocks at the Winkler Ranch include garnetite, hornstones, and marble.

The metamorphosed Playas Peak formation is predominantly marble. The broad band in the hills southwest of the Corbett Ranch is all marble, as is most of the rock along the continuation of this band to the east. Garnetite, hornstone, and andalusite rock are present in the wedge between the porphyritic and seriate porphyritic phases of the stock. The metamorphosed layers in the lower part of the formation, west of the Corbett Ranch, are tremolite-limestone and tremolite-marble beds; the marble equivalents of these beds crop out at the east edge of Granite Pass.

At Hatchet Gap the rock forming the immediate roof of the stock is a white quartzite, partly feldspathized. (See p. 59.) The overlying sandy limestone appears to be unchanged.

IN THE LOWER CRETACEOUS VOLCANIC ROCKS

The basalt-breccia layer of the Ringbone shale at the American mine is strongly epidotized, and parts are bleached to a white porcelainlike rock. The whole of the conical hill just west of the mine and the nose extending south in the Hidalgo volcanics also are bleached in places and still more strongly epidotized. Fully 30 or 40 percent of the hill is either epidote or quartz-epidote rock in blebs, veins, and larger masses. Pockets of quartz-epidote rock are as much as a foot or more across, and many areas 10 to 15 feet across are as much as nine-tenths epidotized. The epidotization brings out the layering of the breccia part of the formation, and the original igneous texture can still be recognized in the massive quartz-epidote rock through the presence of pseudomorphic aggregates of dark green epidote in a pale quartz-epidote matrix.

The bleaching of the rock is due to albitization, to conversion of the black hornblende and augite to pale or colorless amphibole and pyroxene, and to an expulsion of the dustlike iron ore. The bleached rock is thickly impregnated with sphene, and some of this mineral evidently represents a reconstitution of the titaniferous content of the iron ore. The augite is in part recrystallized to colorless pyroxene and in part replaced by epidote or colorless amphibole. The original hornblende phenocrysts are replaced pseudomorphically by aggregates of calcite, epidote, and needles of colorless amphibole, one or all. Minute grains of sphene in the pseudomorphs presumably represent the original titanium content of the augite and hornblende. Some hornblende in the bleached rock and throughout the metamorphic zone in general is replaced at least in part by small crystals of pale bluish-green pleochroic amphibole, and in places this mineral is distributed throughout the body of the bleached rocks. Most thin sections of basalt at and near the contact with the sodic facies of the stock contain this bluish-green amphibole as a replacement of the augite and hornblende. The following pleochroic formula is characteristic: X, greenish-yellow; Y, emerald-green; Z, bluish-green; $X<Y<Z$.

Chlorite, epidote, calcite, and here and there a little sericite are present everywhere in the Comanche volcanic rocks in addition to the distinctive alteration next to the intrusive contacts.

RELATIVE AGE

Briefly summarized, it may be said that silication of the sedimentary rocks began before the earliest facies of the intrusive rocks had completely solidified and continued until the satellite dikes had been emplaced and solidified. The evidence at hand may be separated into four groups: (1) The replacement of silicated sediments by monzonite (see p. 60); (2) evidence observed in thin sections of the monzonite of the Sylvanite-Old Hachita stock; (3) details at the contact between the silicated sediments and the igneous rocks; and (4) inferences drawn from the composite nature of the stocks.

The evidence of groups 1 and 2 indicates that silication had started well before the monzonite, the earliest of the intrusive rocks with which metamorphism is associated, had completely solidified. The significance of group 1 needs no further comment. In the preceding pages a sodic pyroxene was mentioned as having been found at one place in a garnet-ilvaite bed at the contact. The monzonite immediately adjacent contains many grains of a peculiar green pyroxene apparently identical with the sodic pyroxene of the garnet bed, and the presumption is that it was derived from digested blocks of the metamorphic rock. Some grains are included in the plagioclase, and, if xenocrysts, were therefore incorporated into the monzonite before completion of the plagioclase stage of consolidation. It may be suggested that the grains of green pyroxene are altered grains of original augite rather than foreign inclusions, but that seems unlikely in view of the fact that no albitization was observed in the specimen, for it would imply that the sodic solutions causing the alteration had preferentially reconstituted the augite rather than the feldspar. Following is a comparative summary of the optical properties of the pyroxene from the monzonite and from the garnet bed, as measured by Miss Jewell Glass, of the Geological Survey, to show their similarity.

As estimated from the Winchell chart,[65] the mineral contains about 10 percent of the jadeite or acmite molecule.

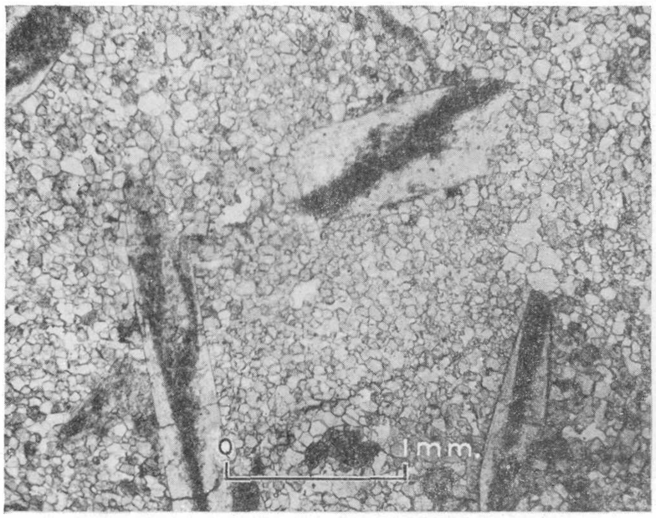
Sodic pyroxene from the monzonite	*Sodic pyroxene from the garnetite*
$\alpha = 1.689$	$\alpha = 1.689$
$\beta = 1.700$	$\beta = 1.699$
$\gamma = 1.718$ or 1.719	$\gamma = 1.719$
$\gamma - \alpha = .029$ or $.030$	$\gamma - \alpha = .030$
$Z \wedge c = 47° - 48°$	$Z \wedge c = 43° - 45°$
Pleochroism:	Pleochroism:
X = green.	X = pale green.
Y = bluish green.	Y = bluish green.
Z = yellowish, nearly colorless.	Z = pale yellow.
Dispersion: $r > v$, strong.	Dispersion: none.

Many late and distinct threads containing orthoclase, a trace of microcline, labradorite, and quartz were observed in a thin section of hornfels from the monzonite contact west of the Buckhorn mine. These presumably are stoping threads of monzonite on a microscopic scale and imply that the hornfels was formed before the feldspar-quartz stage of consolidation in the monzonite was completed, corroborating the conclusion drawn from the sodic pyroxene described above. This dating is further supported by a thin section of monzonite from a narrow sill near the main body at Old Hachita, in which the monzonite is strewn with grains of colorless diopside and garnet, some of which are inclusions in the feldspar. The relative date of formation of the diopside and garnet would be much the same, whether they were formed within the magma from assimilated limestone or were derived from limestone already silicated. Megascopically, grains of garnet may be observed at many places in the monzonite near the contact of the stock at Sylvanite.

The third line of evidence carries the metamorphism to a time after solidification and consists of distinct veins of garnet and epidote cutting and replacing the monzonite and quartz monzonite of the Sylvanite-Old Hachita stock and some of the monzonite porphyry dikes at Old Hachita. (See pl. 15, *B*.)

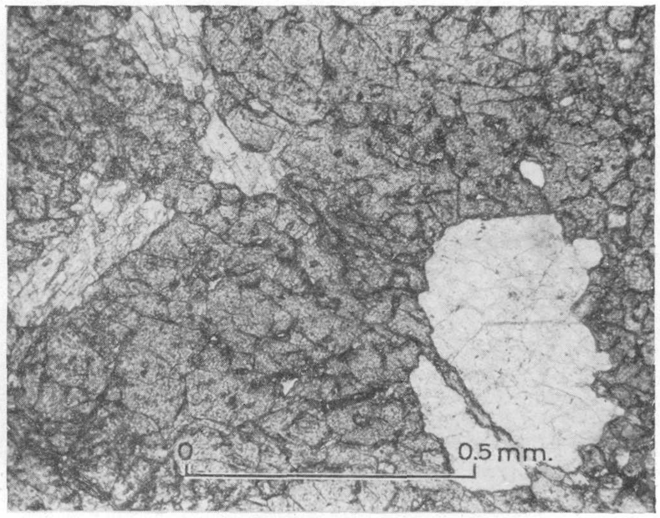
Group four of the evidence accounts for silication at intermediate stages of the general intrusion cycle and in part is corroborative only. For example, it may reasonably be assumed that the quartz monzonite of the Sylvanite stock added something to the silication of the sediments as well as having metamorphosed the monzonite into which it was intruded (see p. 59), and on that assumption there were two stages of metamorphism connected with the Sylvanite stock. Similarly, the silicated rocks at both roof and floor of the Granite Pass stock suggest that each of the two major phases of the granite, which were emplaced at different times, had added something to the metamorphism, and if that is true, the conclusion would follow that metamorphism was

65 Winchell, N. H. and A. N., Elements of optical mineralogy, p. 191, 1927.



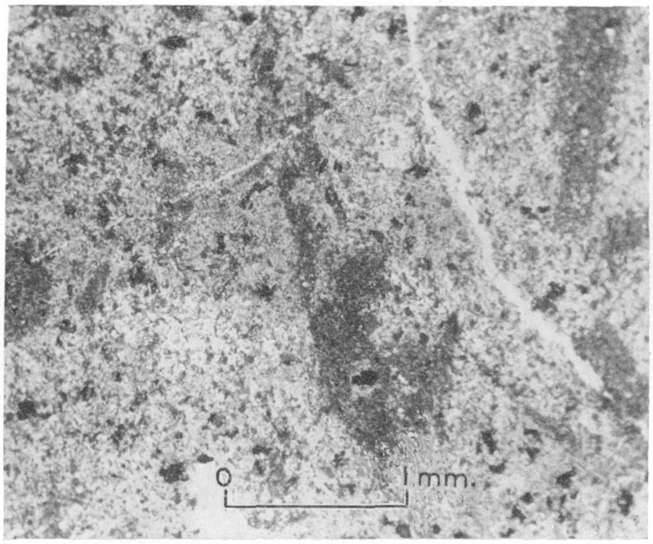
A. SKELETAL CRYSTALS OF TREMOLITE IN MARBLE.

The black cores of the skeletal crystals are composed of very fine-grained calcite. Plain transmitted light.



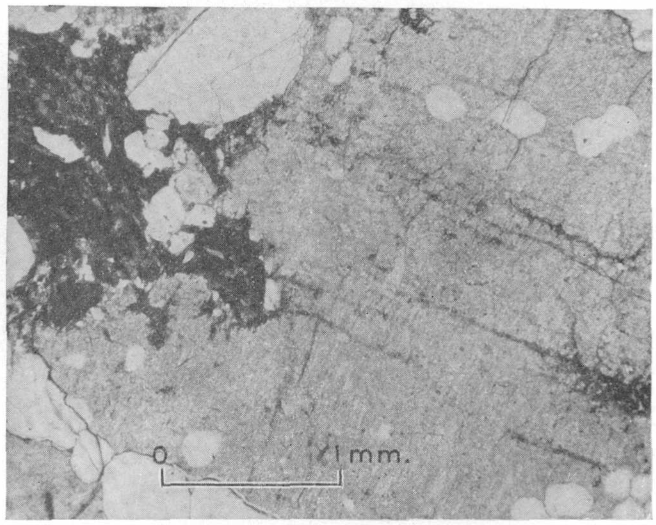
B. THIN SECTION FROM EDGE OF VEIN OF GARNET AND EPIDOTE

Vein cuts and replaces monzonite. In the upper left corner are grains of augite corroded by andradite garnet, and in the lower right corner a stringer of andradite crsoses a large grain of apatite. Plain transmitted light.



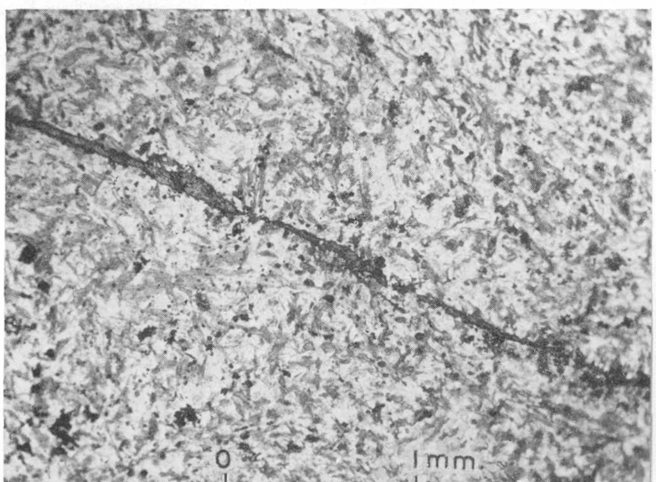
C. METAMORPHOSED LAMPROPHYRE DIKE.

The original hornblende crystals have been pseudomorphically replaced by clusters of minutely crystalline biotite belonging to the metamorphic stage, and other minute crystals of the biotite are scattered through the body of the rock. Plain transmitted light.



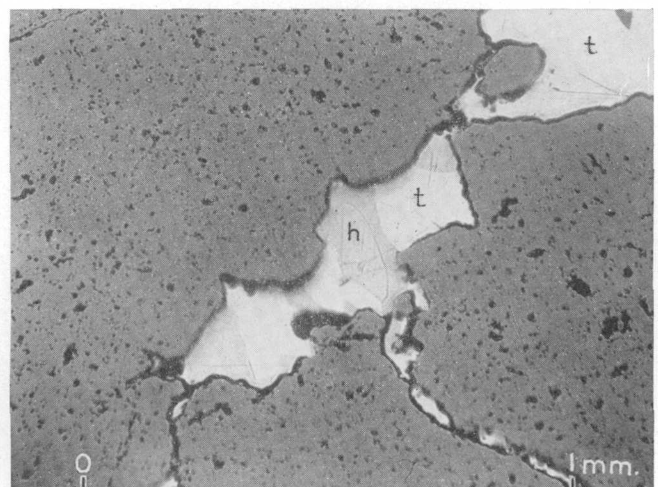
D. PORPHYRITIC GRANITE OF THE GRANITE PASS STOCK.

Shows pockets of recrystallized biotite (dark areas at right and left edges) with threads of the new fine-grained biotite extending across the intervening feldspar Plain transmitted light.



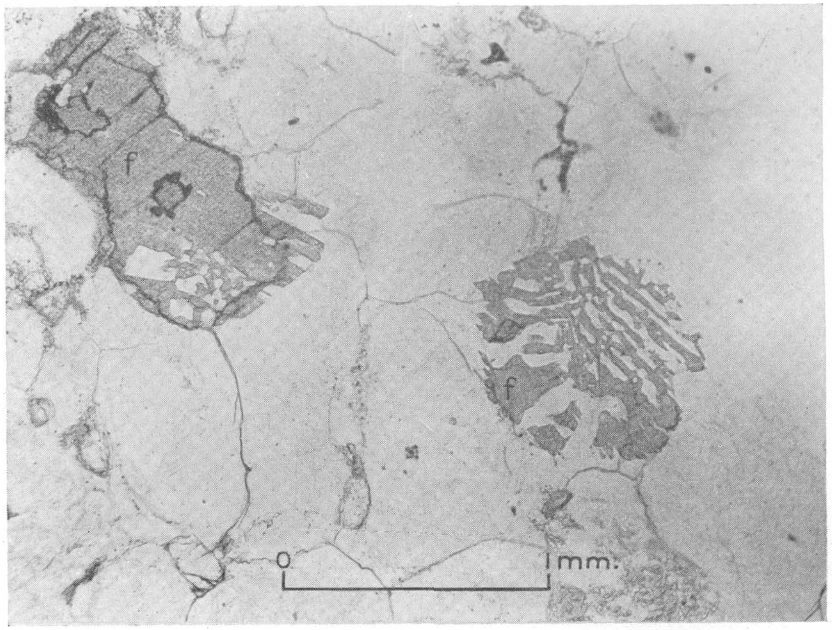
E. LAMPROPHYRE (VOGESITE) CUT BY VEINLET OF SPHENE.

Plain transmitted light.



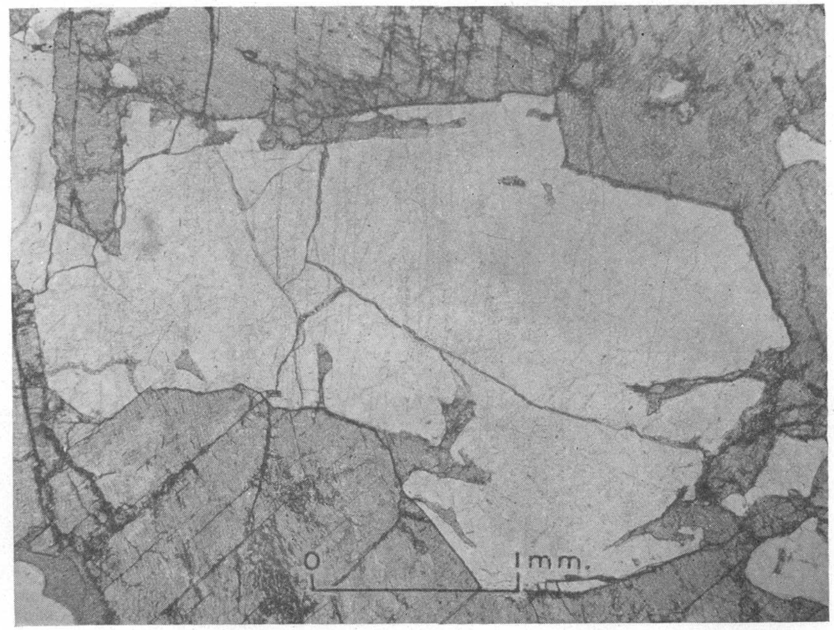
F. ORE FROM LITTLE MILDRED MINE, SYLVANITE DISTRICT.

Shows irregular seam of tetradymite (t) and hessite (h) cutting quartz. Reflected light.



A. PHOTOMICROGRAPH OF FELDSPATHIC QUARTZITE FROM ROOF OF GRANITE PASS STOCK.

Shows replacement nature of the feldspar (f) and development of a pseudomicrographic texture. Plain transmitted light.



B. PHOTOMICROGRAPH OF GRANITE OF GRANITE PASS STOCK.

Specimen was collected from a point about 1 000 feet from the roof contact and shows replacement of quartz (central gray area) by feldspar (microperthite). Plain transmitted light.

C

D

TWO STAGES IN REPLACEMENT AND CONVERSION OF MONZONITE INTO QUARTZ MONZONITE IN THE SYLVANITE STOCK.

C, Ghost blocks of monzonite in rock partly converted to quartz monzonite, the whole cut by threads of quarts monzonite. As seen in the field more distinctly than in the photograph, the central parts of the blocks between the quartz monzonite threads are darker and less rich in quartz monzonite material than the edges. *D* .Stoping threads of quartz monzonite (light), of either replacement or magmatic origin, cutting monzonite (dark).

already under way around the Granite Pass stock before the period of granite emplacement was completed. This conclusion would be true even should the porphyritic facies be entirely a replacement rock (see p. 59), for the seriate porphyritic facies is intruded into it. The fidelity with which the very narrow silicated zone in the Corbett sandstone follows the contact suggests that the metamorphism of that area succeeded emplacement of the seriate porphyritic facies.

The general evidence, then, indicates four stages of metamorphism and suggests a fifth. The first stage started before the monzonite had passed the plagioclase stage of consolidation; a second stage may have been associated with the quartz monzonite, which was injected after complete solidification of the monzonite; another stage was associated with the porphyritic granite of the Granite Pass stock, preceding emplacement of the seriate porphyritic granite; a fourth stage accompanied or followed the seriate porphyritic granite; and the last stage occurred after the satellite porphyry dikes were emplaced. Thus igneous metamorphism, particularly in view of the fact that part of the monzonite, quartz monzonite, and granite are replacement rocks, could be considered a more or less continuous process, immediately related to the general igneous activity but essentially independent of individual pulsations or intrusions, which may have been carriers of the metamorphosing solutions from their point of origin to higher levels in the crust as much as they were generators of such solutions.

INTERNAL ALTERATION OF THE INTRUSIVE ROCKS

Two main types of endomorphism are present in the intrusive rocks, one involving principally the conversion of the original ferromagnesian minerals to those later in the reaction series, and the other leading to the formation of epidote, chlorite, sericite, calcite, and pyrite.

The first type is closely related to the pyrogenic processes of rock formation. In some respects it is like the metamorphism of the Lower Cretaceous volcanic rocks in the inner contact zone. Some details already have been given in the descriptions of the different rocks. The changes include primarily (1) replacement of the original augite and hornblende of the monzonite by needles of a blue-green amphibole apparently identical with that formed in the old volcanic rocks along the contact; (2) replacement of the hornblende of the quartz monzonite by the blue-green amphibole, and recrystallization of the original biotite into clusters of tiny crystals of new pale-brown to green biotite, some of which also replaces original hornblende; and (3) recrystallization of the original biotite of the porphyritic and aplitic facies of the Granite Pass granite into the new green-brown biotite. In the lamprophyre dikes some hornblende is replaced by the new blue-green amphibole, and some hornblende and the original biotite are replaced by a new biotite like that in the stock rocks. In all these rocks the new amphibole and biotite not only replace the original ferromagnesian minerals, in places as pseudomorphs (pl. 15, *C*), but in part are scattered throughout the body of the rock, and the new biotite forms tiny threads or veinlets that follow grain boundaries, cleavage planes of the feldspar, or cut indiscriminately across all minerals. (See pl. 15, *D*.) Such threads also have been observed in aplite dikes. Sphene likewise was developed in all the rocks, including the aplite dikes, at this stage; some of it forms minute stringers cutting the rock (see pl. 15, *E*), and some constitutes distinct reaction rims around grains of magnetite. A high titania content seems to be a family trait of the rocks of the Little Hatchet Mountains, and in general this secondary sphene presumably was formed by a reconstitution of the titanium of the original minerals, but the presence of vein-stage sphene in the Sylvanite district (see p. 71) suggests the possibility that some titanium was introduced.[66]

This type of alteration is most intensely developed in the quartz monzonite on the north slope of Stone Cabin Gulch. In most of this mass the original hornblende and biotite were completely destroyed and the rock now contains scattered phenocrysts of feldspar in a fine-grained and glistening black groundmass largely composed of innumerable tiny crystals and clusters of the brownish-green biotite. A few splintery crystals of the late greenish-blue hornblende are present.

The other type of endomorphism is identical with that found in the plutonic rocks of most mining districts, though in general it is not nearly so strong here as in many other places. It requires very little description beyond that already given in the petrographic descriptions of the different rocks. Briefly, it involves the replacement of the ferromagnesian minerals by chlorite, calcite, and epidote, with the separation of some of the iron as magnetite and of the titanium as sphene and leucoxene; the replacement of the feldspars by epidote, calcite, sericite, and occasionally chlorite; and the introduction of pyrite, which is scattered indiscriminately throughout the rock. The epidote ranges from colorless clinozoisite, which is essentially restricted to the feldspar minerals, to deep-green pistacite that belongs at the extreme iron-rich end of the series and that is essentially confined to the ferromagnesian minerals. This type of endomorphism is like and related to the alteration of the Hidalgo volcanics away from the immediate contact zone.

The Sylvanite stock at the monzonite-quartz monzonite contact exhibits an extreme development of this type of alteration, though not strictly endomorphic. The monzonite in the contact zone has been flooded by deep-green epidote, which forms massive veins as much as 4 inches thick and pods and irregular masses as much as a foot across. The epidote stops sharply at the quartz monzonite or continues into it only along relatively tight joints. (See fig. 10.) Chemical analyses (see pp. 30, 31) show that the monzonite and quartz monzonite have an essentially equal content of iron, so that the concentration of epidote in the monzonite can hardly be due to a greater original amount of iron in that rock, and this consideration coupled with the restriction of intense epidotization to the contact zone suggests that the epidote was formed by reaction with iron-bearing solutions from the quartz monzonite. In the

[66] Gilluly, James, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U. S. Geol. Survey Prof. Paper 173, pp. 112–114, 1932.

abundance of epidote, the alteration here resembles the epidote metamorphism of the Lower Cretaceous volcanic rocks in the immediate contact zone.

Another example of extreme endomorphism seems to be the pyritic alteration of the sodic facies of the monzonite at Old Hachita and similar alteration in part of the Sylvanite stock. In the Sylvanite district, just east of Cottonwood Spring, is a strip about 3,000 feet long and 500 to 1,000 feet wide in which the monzonite is bleached, stained with limonite and jarosite, and in general resembles the jarositized sodic facies of the monzonite at Old Hachita. Pyrite casts can be seen in the most altered rock, and pits and shafts below the shallow weathered zone disclose much pyrite distributed in sericitized rock. Fresh lamprophyre dikes, of more than one variety, cleanly cut the bleached and jarositized rock, and the impression in the field is strong that the dikes were injected after pyritization of the monzonite. But the lamprophyre dikes are pre-ore (see section on ore deposits, Sylvanite district), and therefore if the pyritic and associated alteration of the monzonite is indeed pre-lamprophyre it must be distinctly earlier than the ore-forming stage.

mineral should have been readily accomplished by the monzonite.

Direct evidence of replacement, however, is more abundant and impressive. It consists essentially of a contact zone of hybrid rock, as much as 2,000 feet wide at one place, bordered on one side by readily recognizable monzonite and on the other side by readily recognizable silicated sedimentary rocks. The hybrid rock between has a spotted appearance due to minute grains of white feldspar, and in some parts the feldspar is so abundant that the rock resembles a dark fine-grained monzonite, but there is everywhere something obviously abnormal about its appearance. Conclusive proof that this rock is a hybrid is furnished by the conglomerate in the Howells Ridge formation. All gradations can be traced from unquestionably silicated conglomerate into silicated conglomerate in which the feldspar has begun to sprout both in the matrix and in the pebbles, then into counterfeit monzonite in which only ghostly outlines of the pebbles can be recognized, and finally into rock that the observer feels justified in mapping as real monzonite. The chert pebbles seem to be the last ones to disappear. No hornblende phenocrysts

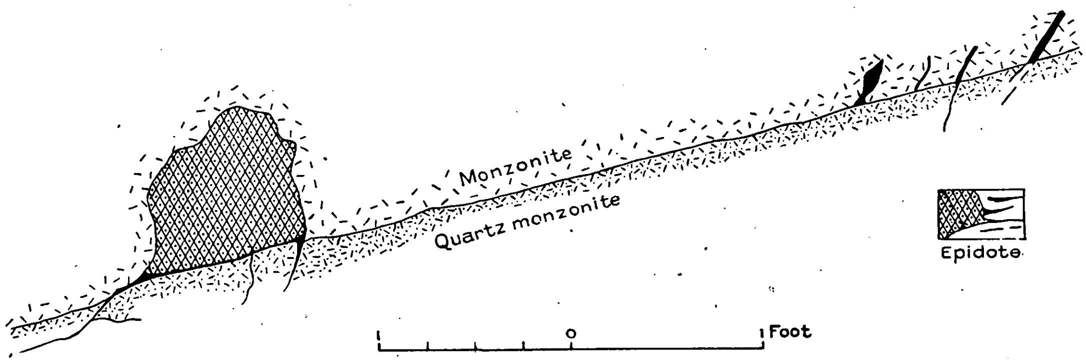


FIGURE 10.—Field sketch showing relative concentration of epidote in the monzonite at the contact of the monzonite and quartz monzonite in the Sylvanite stock.

ASSIMILATION AND REPLACEMENT

SEDIMENTARY ROCKS

The only positive evidence at hand of igneous assimilation of sedimentary rocks, in the strict sense of the term assimilation, is the presence of the metamorphic minerals diopside, garnet, and a sodic pyroxene in the monzonite of the Sylvanite stock, in part derived from digested pieces of metamorphic rock and perhaps in part formed in place from stopped inclusions of limestone. (See p. 56.) Although this gives no quantitative indication of the importance of the process, by inference it may be concluded that assimilation took place on a rather large scale. As the various mechanical methods of igneous emplacement were inadequate or inoperative in the Little Hatchet Mountains (see p. 48), the companion processes of assimilation and replacement, for both of which evidence is present, must have been important, and it has been suggested that the assimilation of rock already partly replaced by igneous

like those in some of the monzonite were noted in the hybrid rock. The texture seems invariably indistinct, for the outlines of the feldspar grains are not sharply separable from the groundmass, and the groundmass everywhere is fine-grained and very dark, grading into hornfels on the one hand and into so-called monzonite on the other. Some of the hybrid rock still retains the sedimentary structure, both in detail that permits the recognition of bedding in hand specimens, and in a broader way that permits observations of strike and dip. Sills or concordant masses of rock that seems to be clearly monzonite are interlayered with the hybrid rock.

Under the microscope the hybrid rock is seen to have the same indistinct appearance that it has in the hand specimen. Here and there it seems certain that the feldspar, both orthoclase and plagioclase, has replaced garnet and quartz, and, in a specimen already described, scapolite as well, but commonly the feldspar grains have vague or irregular outlines that suggest a sprouting from the hornfels groundmass.

At Hatchet Gap the quartzite at the roof of the Granite Pass stock has been replaced by the porphyritic granite facies of the stock. The contact between granite and quartzite seems to be knife-edged, but the quartzite immediately adjacent contains isolated spots of pink feldspar; some of this quartzite weathers to resemble the granite. Microscopic examination discloses that the feldspar grains are porphyroblasts that have replaced the quartzite, as shown in plate 16, *A*, and microscopic examination of a specimen of granite taken from a point about 1,000 feet from the contact shows that feldspar in it also is a replacement mineral. (See pl. 16, *B*.)

EARLIER INTRUSIVE ROCKS

The quartz monzonite mass above Sylvanite, in the Sylvanite stock, is bordered by metamorphosed monzonite in which the evidence of contact metamorphism and assimilation is strikingly apparent in a zone as much as 200 feet wide. The monzonite in this zone has been impregnated with much black biotite and pink feldspar and so appears distinctly spotted. A network of pink threads and veinlets, generally much less than ½ inch thick, cuts this spotted rock. In places these threads, which in appearance and composition are essentially identical with the quartz monzonite, constitute most of the rock mass, and where impregnation of the parts between the threads is most intense the modified monzonite looks confusingly like the quartz monzonite, though fine-grained and darker. (See pl. 16, *C, D*.)

Microscopically, the augite in the monzonite is rimmed and replaced by a hornblende that seems to resemble the light-colored hornblende of the quartz monzonite more closely than the hornblende of the normal monzonite. The hornblende in turn is partly replaced by a muddy greenish-brown biotite, locally marked with asterism like the biotite of the quartz monzonite. Large irregular flakes of this biotite are also present elsewhere; all the biotite has blunt tongues and threads that follow grain boundaries between the feldspars, and it appears interstitial to and later than the other minerals. The originally fine-grained groundmass is now a coarser-grained granitoid intergrowth of orthoclase and unzoned andesine like the plagioclase of the quartz monzonite, about An_{40} in composition and distinct from the original, generally corroded and zoned phenocrysts of andesine-oligoclase and labradorite-oligoclase. Some of the new plagioclase has grown upon original phenocrysts with optical continuity. Veinlike grains of quartz are interstitial to all the other minerals, including those of the reconstituted groundmass. Parts of the rock are recrystallized to a fine-grained lamprophyric mosaic of orthoclase, plagioclase (whose composition cannot be precisely determined but is presumably andesine), hornblende, and quartz, and local patches consist almost entirely of hornblende.

A larger part of the Sylvanite stock than the contact zone just described may be a similar hybrid rock. Light-colored rock from the central part of sec. 28 and about a mile beyond the halo, though mapped as monzonite and originally classified in the field as transitional between the monzonite and quartz monzonite, proves to be almost identical in thin section with the rock in the halo. Most of the rock exposed in a long tunnel in the arroyo extending west from the Buckhorn mine and near a dike of quartz monzonite in the adjacent sediments, appears to be the spotted rock, and in mapping the quartz monzonite east of Livermore Spring it was found difficult at some places to decide with assurance what was quartz monzonite and what monzonite. Similar doubtful rock appears in the body of the quartz monzonite masses, and at the Handcar tunnel there are blocks of monzonite or of hybrid rock having transitional borders into the typical quartz monzonite and into rock that, though resembling the quartz monzonite, does not seem quite typical.

Imposed on the hybrid quartz monzonite and modified monzonite in the assimilation zone are the two types of endomorphism that have been described as general features. The several steps may be considered as parts of a continuous process, from replacement of monzonite by quartz monzonite, through the two alteration stages and, as described later, apparently through the vein-forming stage as well.

ORE DEPOSITS

INTRODUCTION AND CLASSIFICATION

All deposits of the Little Hatchet Mountains, as explored to 1937, are either small or of such type as to have no commercial significance. None of the mines extended much below water level, and those that did were flooded. Consequently, observations were confined to a very shallow zone at isolated places where some favorable feature induced the prospector to penetrate below the surface. Moreover, all the known shoots of minable size appear to have been mined out, at least to water level, so that their characteristic features must be largely inferred.

Casual reference has been made in preceding chapters to three periods or stages of mineralization. The first was the period of ore formation and was immediately related to the late Cretaceous or early Tertiary period of igneous activity. The other two, both trivial, are associated with the Miocene (?) rocks—the first with the felsite and earlier latite dikes, which are later than the ore deposits, and the second with the flow rocks, which were deposited after the rocks and deposits of both earlier stages had been truncated by erosion.

The deposits of the ore-forming period are most naturally classified into those of the Eureka and Sylvanite districts, and this classification is also appropriate from the standpoint of mineral content and commercial treatment. Although in a general way the deposits within each district are largely of the same type, there is such a wide diversity in details that the deposits may be further classified, naturally and readily, into almost as many subtypes as there are mines. In the Sylvanite district there are ten subtypes, and in the Eureka district there are seven. Much of the supposed diversity, however, seems due to limited exposure; were the mines deeper or were the veins more continuously explored, both the Eureka and Sylvanite districts would be more uniform. It is probable, too, that the mineralogic ties between the two districts would be more broadly exposed and the differences less distinct.

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In view of this diversity, a discussion and description of the ore deposits must be largely a description of individual ore bodies, and inasmuch as detailed descriptions of the mines and prospects are given elsewhere in this report, the present section is chiefly designed to show the relations between the kinds of deposits within each district and the relation between the Eureka and Sylvanite districts as units. It would be advantageous to the reader if, before considering those relations, he were to examine briefly the different mine descriptions. A detailed section on mineralogy is included as a background for an understanding of the mine descriptions and of the other sections dealing with the ore deposits.

Oxidation and erosion of the original deposits have given rise to two special types, both of meager economic importance; these are the gold placer deposits of the Sylvanite district and the turquoise deposits of the Eureka district. The full generalized classification of the deposits of the range is as follows, the more detailed subclassifications of the deposits in the Eureka and Sylvanite districts being given elsewhere, in the appropriate sections:

- Late Cretaceous or early Tertiary deposits.
  - Deposits of the Sylvanite district, including vein, replacement, and disseminated types.
  - Deposits of the Eureka district, including vein, limestone replacement, and disseminated types.
- Miocene (?) deposits.
  - Felsite and latite dikes showing meager alteration by sericite and pyrite.
  - Veins in the extrusive rocks.
- Deposits derived by oxidation and erosion.
  - Gold placer deposits.
  - Turquoise deposits.

MINERALOGY

The differences and similarities between the Eureka and Sylvanite districts and between individual deposits in each district, as mentioned above, are largely based on mineralogy—in part upon the ore minerals and in part upon significant gangue minerals and assemblages. Consequently, the ore and gangue minerals are separately considered in the mineralogic descriptions below. The minerals of the original deposits, which were formed by hot waters or vapors related to the igneous bodies (see p. 79) and tending to rise toward the surface (hypogene minerals), are distinguished from those derived from the original deposits by weathering processes after being exposed or brought close to the surface by erosion (supergene minerals).

Two lists of the minerals are given below for ready reference, one listing them alphabetically and the other in the form of a chart giving them by districts, metals, and origin and showing their comparative importance. These lists include only those minerals formed during the processes of mineralization, both hypogene and supergene; they are exclusive of primary rock-making and metamorphic minerals, which have been described elsewhere. The point of separation between metamorphism and ore formation as chosen for this report has been defined on p. 53.

Minerals of the ore deposits of the Little Hatchet Mountains listed alphabetically

Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$ (See detailed description.)
Albite	$NaAlSi_3O_8$
Anglesite	$PbSO_4$
Arsenopyrite	$FeAsS$
Asbestos. See chrysotile.	
Aurichalcite	$2(Zn,Cu)_5(CO_3)_2(OH)_2$
Azurite	$Cu_3(CO_3)_2(OH)_2$
Barite	$BaSO_4$
Biotite	$K(Mg,Fe)_3(AlSi_3O_{10})((OH),F)_2$
Bismutite	$Bi_2O_3.CO_2.H_2O$ (?)
Calcite	$CaCO_3$ (See detailed description.)
Cerargyrite	$AgCl$
Cerussite	$PbCO_3$
Chalcanthite	$CuSO_4.5H_2O$
Chalcocite	Cu_2S
Chalcopyrite	$CuFeS_2$
Chlorite	Hydrous silicate of iron, magnesium, and aluminum.
Chrysocolla	$CuSiO_3.2H_2O$
Chrysotile	$Mg_3Si_2O_5(OH)_4$
Copper arsenates.	
Covellite	CuS
Epidote	$Ca_2(Al,Fe)_3(SiO_4)_3(OH)$
Fluorite	CaF_2
Galena	PbS
Gold (native)	Au
Hematite	Fe_2O_3
Hessite	Ag_2Te
Jarosite	$KFe_3(SO_4)_2(OH)_6$
Limonite	(See detailed description.)
Magnetite	Fe_3O_4
Malachite	$Cu_2CO_3(OH)_2$
Manganosiderite	$(Fe,Mn)CO_3$
Melanterite	$FeSO_4.7H_2O$
Mimetite	$Pb_5Cl(AsO_4)_3$
Molybdenite	MoS_2
Mottramite	$Pb(Cu,Zn)VO_4(OH)$
Muscovite	$KAl_3Si_3O_{10}(OH)_2$
Olivenite	$Cu_2AsO_4(OH)$
Orthoclase	$KAlSi_3O_8$
Plumbojarosite	$PbFe_6(SO_4)_4(OH)_{12}$
Psilomelane	$(Ba,Mn)_2Mn_8O_{16}(OH)_4$
Pyrite	FeS_2
Pyrolusite	MnO_2, with adsorbed impurities, chiefly water.
Pyrrhotite	Fe_7S_8
Quartz	SiO_2
Scapolite	An isomorphous series ranging from marialite (Ma), $Na_4Al_3Si_9O_{24}Cl$, to meionite (Me), $Ca_4Al_6Si_6O_{24}(CO_3)$
Scheelite	$CaWO_4$
Scorodite	$FeAsO_4.2H_2O$
Sericite. See muscovite.	
Silver (native)	Ag
Smithsonite	$ZnCO_3$
Specularite. See hematite.	
Sphalerite	Zns
Sphene	$CaTiSiO_5$
Stibnite [1]	Sb_2S_3
Tetradymite	Bi_2Te_3
Tetrahedrite	$Cu_{12}(Sb,As)_4S_{13}$
Tourmaline	A complex borosilicate of aluminum and other bases.
Turquoise	$CuAl_6P_4H_{18}O_{20}$
Vermiculite	Hydrous silicate of aluminum, iron, and magnesium.
Wad	Mixtures of oxides of iron and manganese with water.
Wolframite [1]	$(Fe,Mn)WO_4$

[1] Reported, but not found during the present survey. See detailed descriptions.

Minerals of the ore deposits of the Little Hatchet Mountains, listed by districts, metals, and origin

[Capitals indicate minerals characteristic of the district as a whole, though possibly present only in minor amounts, thus, "HESSITE"; italics indicate minerals characteristic of a particular type of deposit only, thus, "*Barite*"; lower-case letters indicate minerals present but neither common nor characteristic, thus, "Magnetite"]

Ore minerals

Metal	Gold		Silver		Copper	
District	Sylvanite	Eureka	Sylvanite	Eureka	Sylvanite	Eureka
Supergene	Native gold	Native gold		Cerargyrite Native silver	Azurite Chalcanthite Chalcocite Covellite Malachite Mottramite	Aurichalcite Azurite Chalcanthite Chalcocite Covellite Malachite Mottramite Copper arsenates Olivenite *Turquoise*
Hypogene	In auriferous sulfides NATIVE GOLD	In auriferous sulfides	HESSITE In argentiferous sulfides	In argentiferous sulfides	CHALCOPYRITE	Chalcopyrite *Tetrahedrite*

Ore minerals—Continued

Metal	Lead and zinc		Iron and manganese		Arsenic	
District	Sylvanite	Eureka	Sylvanite	Eureka	Sylvanite	Eureka
Supergene	Anglesite Cerussite Mimetite Mottramite Smithsonite	ANGLESITE Aurichalcite CERUSSITE Mottramite Plumbojarosite *Smithsonite*	Hematite *Jarosite* LIMONITE Melanterite *MANGANESE OXIDES* *Scorodite*	*Jarosite* LIMONITE *MANGANESE OXIDES* *Scorodite*	Mimetite *Scorodite*	Copper arsenates *Scorodite*
Hypogene	*Galena* Sphalerite	GALENA SPHALERITE	ARSENOPYRITE IRON- AND MANGANESE-BEARING CALCITE Magnetite PYRITE *Pyrrhotite* Specularite	*Arsenopyrite* IRON- AND MANGANESE-BEARING CALCITE PYRITE MANGANOSIDERITE *Specularite*	ARSENOPYRITE	*Arsenopyrite* *Tetrahedrite*

	Ore minerals—Continued		Gangue minerals			
Metal	Antimony, bismuth, molybdenum, tellurium, tungsten, vanadium		Silicates		Others	
District	Sylvanite	Eureka	Sylvanite	Eureka	Sylvanite	Eureka
Supergene	BISMUTITE Mottramite	Bismutite Mottramite			Calcite Quartz	Calcite
Hypogene	HESSITE Molybdenite *Scheelite* TETRADYMITE	*Scheelite* Stibnite[1] Tetradymite *Tetrahedrite* Wolframite[1]	ACTINOLITE ALBITE Asbestos Biotite CHLORITE Epidote MUSCOVITE Orthoclase Scapolite SPHENE (TITANITE) TOURMALINE	Chlorite Muscovite SERICITE Vermiculite	*Barite* CALCITE Fluorite QUARTZ	BARITE CALCITE MANGANOSIDERITE QUARTZ

[1] Mentioned in earlier reports but not found during the present survey. See detailed descriptions.

GOLD

Native gold, of hypogene origin, is the most important constituent of the veins of the Sylvanite district. It forms rough grains, scattered in the quartz and calcite of the vein matter, and clusters and threads that cut those minerals. It is closely and apparently invariably associated with tetradymite, bismuth telluride, which thus is a guide to its presence. At places it is intergrown with the tetradymite in a way suggesting contemporaneous deposition. The gold and tetradymite represent the latest stage of deposition in the Sylvanite veins.

Many of the gold particles are of microscopic size, but a large number are readily visible to the naked eye; nuggets as much as 1/16 inch in diameter have been observed in place, and still larger nuggets have been collected from placer gravels nearby. A. M. Morgan, who was in charge of the Little Mildred (Green) mine at the time of my visit in 1935, states that he has seen pockets as much as ½ inch thick and 8 inches long in which the gold constituted about half the volume. Porous masses of similar size and apparently representing similar pockets from which the gangue has been removed, are said to have been collected from the placers. Such specimens, however, are rare.

Nuggets from the Little Mildred mine were tested and found to be 0.953 fine, and an assay of several grains from the Gold Hill mine indicated an average fineness of 0.936. An assay of a little placer gold indicated a fineness of 0.949, and Jones[67] reports that the average fineness of the placer gold mined in the boom days of Sylvanite was about 0.930.

No native gold of hypogene origin is present in the Eureka district, but most sulfides of both districts contain at least traces of gold, which are liberated on oxidation. In none of the sulfides, however, is the gold content high enough to contribute an appreciable amount to the ore. In the Sylvanite district, for example, a sample of chalcopyrite from the Buckhorn mine yielded only a trace of gold and silver combined, and the ore of the Copper Dick mine, consisting almost entirely of chalcopyrite, contained on the average only 0.02 ounce or less of gold a ton. A specimen of galena from the Silver Trail tunnel is said by the owner of the mine to have assayed 0.1 ounce a ton. In the Eureka district a specimen of massive pyrite from the Eighth of March shaft was found to contain neither silver nor gold, and pyrite of a later stage was found to contain only on the order of 0.015 ounce a ton. Gold assays as high as 0.6 ounce a ton have been reported from veins of the Eureka district, but the average seems to be only 0.03 ounce or less a ton.

SILVER

HYPOGENE MINERALS

Hessite, silver telluride, not previously reported from the Little Hatchet Mountains, is intimately intergrown with tetradymite at the Little Mildred mine in the Sylvanite district. It is so thoroughly masked by the tetradymite as to be recognizable only under the microscope. (See pl. 15, *F*.) It is responsible for the comparatively high silver content of the Little Mildred ore, and to judge from the small silver content of the other ore minerals of the district, as described below, may likewise account for the silver content of some of the other tetradymite-bearing ores, though it was not recognized in them.

All the base-metal sulfides of both the Sylvanite and Eureka districts contain at least traces of silver, and in the Eureka district they account for the entire original silver content of the ores. Tetrahedrite and galena apparently are the greatest silver contributors. No quantitative information concerning the tetrahedrite is available, but the galena seems to contain about 75 or 80 ounces of silver a ton. In the Sylvanite district, on the contrary, it is doubtful if any appreciable quantity of silver is derived from the base-metal minerals. Tests of chalcopyrite from the Buckhorn mine disclose only a trace of gold and silver combined, and at the Copper Dick mine, where the ore minerals include only massive chalcopyrite and subordinate pyrite, the silver content ranged only from 0.5 ounce to 2 ounces a ton though the ore carried as much as 30 percent of copper. A 2-ton shipment of sorted galena ore from the Silver Trail tunnel contained 150 ounces of silver, but galena is so rare in the Sylvanite district that it can hardly account for much of the silver in the other mines there.

SUPERGENE MINERALS

Cerargyrite.—Crusts of green and yellow cerargyrite, horn silver, are prominent in cracks and joints of chalcocite ore from the Silver Queen shaft in the Eureka district. It is said to have been present in the earlier shipments from the American and King mines and may be found also in the oxidized parts of the other silver-bearing veins of the Eureka district.

Native silver.—Wire silver is said to be present in the American vein at the bottom (250-foot) level of the main shaft, which is under water, and it is reported that native silver was present in the ore mined from just above water level at the King mine. Native silver is said to have been found in the Jowell vein of the Sylvanite district.[68]

Other minerals.—The lead carbonate ores of the Hornet and Wasp mines apparently contained generally from 25 to 50 ounces of silver a ton, and as much as 140 ounces a ton has been reported.

The silver of the leached and mixed ores of the Buckhorn mine of the Sylvanite district must be mainly supergene, and the high silver of the ore at the King 400 mine presumably was due to supergene enrichment.

COPPER

HYPOGENE MINERALS

Chalcopyrite.—Chalcopyrite is present in all the deposits, of all types, in the Sylvanite district and is generally the most abundant sulfide. It is particularly prominent at the Gold Hill mine, though constituting only a small part of the vein matter, and is still more abundant at the Buckhorn mine,

[67] Jones, F. A., The new camp of Sylvanite, N. Mex.: Min. Sci., vol. 58, pp. 489-490, 1908.

[68] Hill, J. M., in Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 341, 1910.

where it forms massive chalcopyrite-rich slabs as much as a foot thick. Equally large slabs of massive chalcopyrite are closely associated with coarse-grained and massive barite at the Santa Maria tunnel near Livermore Spring. At the Copper Dick mine chalcopyrite constituted replacement bodies in garnetite containing as much as 30 percent of copper in carload lots, which is close to the copper content of pure chalcopyrite. A little chalcopyrite, apparently of contact-metamorphic origin, is intimately associated with ilvaite in a garnet bed at the monzonite contact west of the Copper Dick mine.

Chalcopyrite is associated with the other sulfides in most of the veins of the Eureka district, at least in traces, but at no place in that district does it even approach commercial importance. In both districts some chalcopyrite forms microscopic grains and threads in sphalerite, but the particles are much too small to be liberated, and thus are inevitably lost to the miner.

Tetrahedrite.—Tetrahedrite appears to have been one of the most abundant of the sulfides at the Silver King mine in the Eureka district. It is admixed with the other sulfides but appears to be distinctly later than the sphalerite and earlier than the pyrite, chalcopyrite, and galena.

According to A. J. Fitch, owner, tetrahedrite was common in the stopes below water level at the King 400 mine, and the silver of the ore was associated with it. A little copper arsenate on the dump of the Howard shaft and in a shaft near the southeast corner of the Virginia claim suggests the presence of tetrahedrite at those two places.

The tetrahedrite, to judge from Fitch's statement, probably contributes a good deal of the silver content of the tetrahedrite-bearing veins. No assays of pure tetrahedrite are available to corroborate this assumption nor can specimens be obtained large enough for critical results, but a qualitative analysis of one specimen proves that silver is present.

SUPERGENE MINERALS

Aurichalcite.—A few pearly-green tufts and nodular incrustations of aurichalcite were found on a piece of oxidized vein matter on the dump of the King Gold No. 2 shaft, in the Eureka district.

Azurite and malachite.—Small quantities of azurite and malachite, the blue and the green copper carbonates, are present in outcrops and oxidized parts of the deposits of both the Eureka and Sylvanite districts. Their occurrence is typical of these minerals and no special description is needed other than to mention that some malachite at the Faria workings is pseudomorphic after small rhombic crystals of supergene calcite.

Chalcanthite.—Traces of chalcanthite, the hydrous copper sulfate known as "blue vitriol", were seen at one or two places in both the Eureka and Sylvanite districts in protected underground localities where it could have been formed by evaporation of copper sulfate waters.

Chalcocite and covellite.—Chalcocite (copper glance) is present in most of the deposits, roughly in proportion to the original copper minerals present. It was an important ore mineral at the Silver Queen shaft and at the King 400 mine in the Eureka district and doubtless accounts for a good part of the copper content of the ore at the Buckhorn mine in the Sylvanite district.

The chalcopyrite from all deposits shows at least slight replacement by chalcocite. Only microscopic traces of covellite have been noted.

Chrysocolla.—Small amounts of chrysocolla were observed on some of the mine dumps of the Sylvanite district, where copper minerals are most abundant. It seems to be most prominent at the Faria workings near Livermore Spring.

Copper arsenates.—Stains of an undetermined olive-green copper arsenate were observed in oxidized ore on the dump of the Howard shaft in the Eureka district. It must indicate the presence of tetrahedrite or arsenopyrite in the Howard vein.

Deep-green glassy olivenite, a basic copper arsenate, is conspicuous in a shallow shaft near the southeast corner of the Virginia claim, also in the Eureka district. It appears to be breaking down into a bright-green earthy copper arsenate of undetermined mineralogy. In the absence of any evidence of scorodite, indicative of arsenopyrite, the copper arsenates are believed to have been derived from tetrahedrite.

Mottramite.—See under vanadium minerals.

Turquoise.—Threads of turquoise, a hydrous phosphate of aluminum and copper, cut the walls of oxidized veins in parts of the Eureka district. The turquoise was at one time of commercial interest as a gem mineral.

The turquoise deposits are described on pp. 83-84.

LEAD

HYPOGENE MINERALS

Galena.—Galena is rare in the Sylvanite district, except at one prospect, but in the Eureka district it is perhaps the most important of the ore minerals.

It has been observed in microscopic grains in polished specimens of ore from the Gold Hill mine in the Sylvanite district, and fine-grained galena was observed in a half-inch stringer in the Little Mildred vein. It is the most abundant ore mineral at the Silver Trail tunnel, where it occupies fairly pure streaks as much as 8 inches wide; there it is comparatively coarse-grained, forming cleavage pieces as much as 1 inch on edge, and an assay of one sample is said to have indicated 110 ounces of silver and 0.1 ounce of gold a ton. At each of those three places the galena is associated with sphalerite, which it generally veins, and with chalcopyrite, with which it seems contemporaneous. At the Silver Trail tunnel it is associated also with pyrrhotite.

In the Eureka district the galena is in part intimately mixed with sphalerite, tetrahedrite, and a little chalcopyrite and in part forms pure streaks a foot or more thick. It is younger than the sphalerite and tetrahedrite, but appears to be of the same age as the chalcopyrite and some pyrite. A few assays of high-grade galena ore and of lead concentrates suggest that the galena may contain between 80 and 140 ounces a ton in silver.

Galena was one of the chief original constituents of an irregular replacement deposit in limestone at the Hornet mine.

SUPERGENE MINERALS

Anglesite and cerussite.—A little anglesite, the first product of oxidation of galena, is present in normal characteristic association with galena. Cerussite likewise is present wherever galena was originally present, and it constituted minable ore bodies in the Eureka district, particularly at the American, Wasp, and Hornet mines. At the Wasp and Hornet mines the cerussite ores are said to have contained generally from 25 to 50 ounces of silver a ton and to have yielded fully 140 ounces a ton.

Mottramite.—See under vanadium minerals.

Mimetite.—Yellow interlacing, hairlike needles of mimetite, giving a strong positive test for arsenic and a negative test for vanadium, were observed on cerussite at the Silver Trail tunnel in the Sylvanite district.

Plumbojarosite.—Wide streaks of plumbojarosite, a yellow, minutely crystalline to earthy, basic lead-iron sulfate, are associated with partly oxidized galena in a shallow shaft 2,000 feet due west of Old Hachita and on the south link of the Old Hachita fault vein.

Plumbojarosite resembles jarosite, the potassium-iron member of the jarosite family, from which it may be distinguished only by optical or chemical analysis, and it may be present more widely than recognized. Any large quantities of jarosite in the veins should be tested for lead, for not only would the plumbojarosite, if present, indicate the original presence of galena, but plumbojarosite in itself may contain enough lead to be an important ore mineral.

ZINC

HYPOGENE MINERALS

Sphalerite.—Sphalerite, like galena, is rare in the Sylvanite district but is an important constituent of the most productive veins of the Eureka district. It is associated with galena in each of the three locations in the Sylvanite district mentioned for galena, and the presence of 0.1 to 0.5 percent of zinc in the Buckhorn ore as reported in smelter returns indicates that sphalerite is present there also.

In the Eureka district sphalerite was sufficiently abundant at the American mine to yield commercial quantities of zinc concentrate. To judge from the deposits of zinc carbonate ores at the Hornet and Wasp mines, it must have been abundant at those mines also, and it appears to be the most abundant sulfide at the Miss Pickle prospect.

The sphalerite is commonly the black iron-bearing variety closely akin to the variety marmatite, and much of it contains the microscopic blebs of chalcopyrite that seem characteristic of sphalerite in the deposits of the Western States. The silver content of the sphalerite seems to be insignificant.

SUPERGENE MINERALS

Aurichalcite.—See under copper minerals.

Mottramite.—See under vanadium minerals.

Smithsonite.—Smithsonite, in part the variety known as dry-bone ore, constituted one of the three varieties of ore mined at the Hornet mine, and spots of dry-bone ore mark the walls of the old lead carbonate stope at the Wasp mine nearby. Zinc-carbonate ore is said to have been mined from the upper levels of the American mine during the early days.

A little botryoidal white smithsonite lines the walls of cavities in oxidized ore at the Silver Trail tunnel in the Sylvanite district, where it was precipitated by the calcite gangue. The oxidized ores mined at the Buckhorn mine contain an average of 0.14 percent of zinc, which presumably is present as smithsonite.

IRON

HYPOGENE MINERALS

Arsenopyrite.—See under arsenic minerals.

Pyrite.—Pyrite is present in all deposits of both the Eureka and Sylvanite districts.

In the Eureka district two varieties of pyrite are present, one early in the mineral sequence and the other distinctly late. The earlier pyrite is a pale variety whose crystal form, wherever recognizable, seems to be the cube. It is scattered as fine-grained particles or clusters in the quartz stringers characterizing the narrower and less productive parts of the veins, and similar fine-grained pale pyrite is mixed with the zinc, lead, and copper sulfides in the ore shoots. Polished sections show that the pyrite is the earliest of the common sulfides; but its relation to the arsenopyrite of the American mine is uncertain.

Massive pyrite of this variety seems abundant on a part of the American dump and on the Bonanza and Eighth of March dumps, at all those places forming veins and stringers, with or without quartz and calcite, cutting the monzonite wall rock. It is particularly prominent at the Bonanza mine, where some pyrite veins were as much as a foot or more wide. This massive material is made up of small grains so loosely held together that they disintegrate readily into a pyrite sand.

The other variety of pyrite in the Eureka district is yellower and almost invariably occurs as well-formed pyritohedrons, a crystal form made up of twelve faces each having five edges. These crystals range from the smallest recognizable grains to individuals half an inch across, and they are commonly embedded in the calcite gangue or project into calcite druses; a few crystals line other small cavities in the vein matter. This variety of pyrite is in part contemporaneous with the galena and chalcopyrite of the ore and in part later and was deposited near the end of the mineralization stage.

Two varieties of pyrite are present in the Sylvanite district also, resembling the pyrite of the Eureka district not only in color but in form and age relations as well. The earlier or pale variety is distributed as small grains or clusters in quartz and less commonly in early calcite, and also forms more massive and coarsely granular material distinctly later than those gangue minerals. It occurs alone and, more commonly, in mixtures with chalcopyrite in which the chalcopyrite acts as a cement for the pyrite. As may be observed from the square outlines of crystals embedded in chalcopyrite, from the facile pseudocleavage shown by the clusters, and from the biscuitlike outlines of some grains in polished specimens, the coarsely granular material apparently consists of aggregates of cubic crystals. The distinct crystals disseminated in the gangue all seem to be cubes with octahedral and pyritohedral modifications.

With the probable exception of arsenopyrite and molybdenite this pyrite was the earliest sulfide deposited in the veins of the Sylvanite district.

The late pyrite that is common in the Eureka district has been observed in the Sylvanite district at two places only. At the Creeper mine, thin stringers of calcite containing pyritohedral grains of yellow pyrite, identical with the late pyrite-calcite stringers of the Eureka district, cut pyritized monzonite in which the pyrite is of the pale variety. At the Santa Maria tunnel minute oxidized pyritohedrons are present in calcite-chalcopyrite stringers that vein the predominant quartz-early calcite-barite gangue.

The distinction between the two varieties of pyrite serves a practical purpose. The earlier or pale variety was deposited before the valuable sulfides, and only by chance could it serve the prospector or miner as a guide to their presence; the yellower pyritohedral variety, on the other hand, indicates those veins or parts of veins in the Eureka district that were open during the ore-forming stage of deposition, and it thus offers a chance of leading the miner to the parts in which the valuable minerals were most abundantly deposited.

Assays made of both varieties indicate that the earlier variety is essentially barren of both gold and silver, whereas the later variety contains on the order of 0.015 ounce of gold a ton and 3.5 ounces of silver a ton.

Pyrrhotite.—Pyrrhotite, magnetic pyrites, has been observed at four prospects in the Sylvanite district. At the Clemmie tunnel it has replaced the marmorized cement of a coarse-grained metamorphic quartzite, and microscopic hexagonal crystals of pyrrhotite are embedded in the quartz of gold-bearing stringers at the same prospect. (See pl. 17, *A, B.*) A little chalcopyrite is associated and apparently contemporaneous with the pyrrhotite in the quartzite.

Blebs of pyrrhotite, an inch or less across and veined by galena, chalcopyrite, and sphalerite, are distributed in coarse-grained calcite at the Silver Trail tunnel. Grains of pyrrhotite associated with pyrite, molybdenite, and epidote are present in calcite stringers at the Faria workings nearby, and pyrrhotite is distributed in the altered and pyritized monzonite at the Gold Eagle mine at Broken Jug Pass.

Because of its occurrence at the Clemmie mine, pyrrhotite is classified in the table on page 63 as being characteristic of a particular type of deposit, but to judge from its presence in the other types as well, it may be present in minute amounts in most veins of the Sylvanite district.

Specularite and magnetite.—Specularite and magnetite are rare in the Sylvanite district, but in the Eureka district specularite is a prominent and characteristic constituent of some deposits. No magnetite has been observed in the Eureka district.

Veinlets and pockets of minutely grained specularite, in part pseudomorphically replaced by magnetite and associated with the vein sulfides, cut and replace calcite at the Gold Hill mine. (See pl. 19, *A, B.*) At one of the Faria shafts, massive, bladed magnetite associated with epidote is interstitial to the combs of quartz stringers and is embedded in calcite that also is interstitial to the quartz. The bladed shape of the crystals—some of the blades are half an inch or more in length—suggests pseudomorphism after specularite. Microscopic examination fails to disclose any original specularite, but the magnetite is changed to later hematite along irregular cracks and octahedral parting planes. Similar bladed crystals of magnetite fully an inch or more in length are present at some of the workings on the Copper Dick claim. At these and at the main Copper Dick workings, minute isometric crystals of magnetite were produced as one product of the hydrothermal alteration of the garnetite wall rock.

A trace of magnetite was found in one of the tight footwall spurs of the Handcar vein above Sylvanite, and magnetite is associated with chalcopyrite at a small copper prospect near the top of the range in the porphyritic granite south of Granite Pass. Hill [69] reports that magnetite was obtained from pannings of oxidized ore from the Buckhorn vein.

In the Eureka district considerable specularite, associated with barite, quartz, and calcite, is present on the dump of a shallow filled pit in the Hidalgo volcanics at the south edge of Old Hachita. The two dumps on the Eighth of March vein just west of the arroyo have specularite, and this mineral seems typical of the Silver Tree vein southwest of the Ringbone Ranch and of the other veins nearby to the east, all in the Hidalgo volcanics. A little specularite was noted on the dump of the old Silver Bell prospect in the Broken Jug limestone south of the Hornet mine. The variety of specularite in these occurrences in the Eureka district is fine-grained and micaceous, has a slightly greasy feel, and occurs in plates so thin as to be blood red.

In secs. 2 and 11, southwest of the American mine, a great part of the andesite breccia layer in the Howells Ridge formation and much of the underlying diorite sill and adjacent sediments are impregnated with specularite, in company with much sericite and quartz. The disseminated specularite is microscopically fine-grained, but in addition the rock is cut by threads of hard coarse-grained specularite and by quartz-specularite stringers in which some of the hard specularite blades are ¼ inch or more long. The sedimentary layer of the Hidalgo volcanics is similarly mineralized near hill 5654, and specularite with quartz is present in one of the veins in the Hidalgo volcanics on the east slope of hill 5150. (See p. 78.)

All these places in the Eureka district, except the Silver Bell prospect, lie within or against some of the Lower Cretaceous volcanic rocks, and the Silver Bell prospect itself is only about 200 feet from the Hidalgo volcanics.

Manganosiderite.—See under gangue minerals.

SUPERGENE MINERALS

Hematite.—The kaolinized lamprophyre footwall in the bottom workings of the Buckhorn mine is spotted with red earthy hematite derived from

[69] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 341, 1910.

oxidation of pyrite originally disseminated in the lamprophyre.

Limonite.—The term "limonite" is used here to include all the amorphous hydrated iron oxides commonly present in the oxidized parts of ore deposits.

In the Little Hatchet Mountains the limonite ranges from red and yellow-brown earthy material to hard, varnishlike and boxwork varieties. In places it is considerably admixed with black manganese oxides and thus grades into wad, particularly in the Eureka district where much iron and manganese oxides are derived simultaneously from the manganosiderite gangue. At many places also it is mixed with or contains streaks of jarosite, and in the arsenopyrite-bearing veins it is mixed with scorodite.

Most of the oxidized ore mined at the Buckhorn mine consisted of brittle, cindery or spongy limonite boxwork containing cavernous spaces fully 1½ feet in diameter and 3 feet long. The massive deep-brown to black variety of limonite that looks like hardened varnish and that is characteristic of oxidized massive chalcopyrite is common at the Santa Maria and Faria workings and has been observed in minor amounts at many other places. Some ocherous limonite from the Silver Trail tunnel shows a preserved cubic cleavage and is apparently pseudomorphous after galena.

Jarosite.—The basic ferric sulfate, jarosite, a common oxidation product of pyrite in arid and semiarid regions, is common in pyritic veins of the Little Hatchet Mountains and where there has been intense pyritization of the country rock. It is bright yellow to ocherous yellow and brown and in the darker shades may resemble light-colored limonite, with which it is commonly associated and to which it is converted on further oxidation. The purer material may be distinguished from limonite by its soft talcose or graphitic feel. The characteristic hexagonal flakes can be recognized under the microscope for the massive jarosite in the vein deposits, but more commonly in the Little Hatchet Mountains it constitutes apparently amorphous stains.

Jarosite is conspicuous in the area occupied by the sodic facies of the monzonite at Old Hachita and is so characteristic of the weathering of that rock as to be an aid in field mapping. Over most of its outcrop the rock is either altered to a pink, red, or yellow iron-stained and kaolinized rock in which some of the stain is jarositic, or is bleached chalk white and speckled with pockets of jarosite, which are nested in the casts of original pyrite crystals. Yellow nodular pockets that measure inches across and are as much as half jarosite are common. The pyritized monzonite near Cottonwood Spring in the Sylvanite district is similarly altered.

The weathered pyritic parts of the quartz-specularite deposits of the Eureka area (see p. 68) are much like the jarositized rock described above, though containing pockets of purer and more crystalline jarosite. This more crystalline material, in comparatively pure masses or pockets, and having the distinctive talcose feel, is like that in the vein deposits. The largest vein occurrence seems to be along the Stiles vein northwest of Old Hachita (see pl. 12), which contains streaks of jarosite fully a foot wide, and jarosite is particularly noticeable also in the Buckhorn mine in the Sylvanite district.

Melanterite.—Efflorescences of melanterite, iron sulfate, crust the walls of the workings at the Clemmie prospect, where pyrrhotite is the principal ore mineral.

Scorodite.—See under arsenic minerals.

MANGANESE

HYPOGENE MINERALS

The original minerals from which were derived the manganese oxides now present consisted of manganiferous calcite and manganosiderite in the veins and similar carbonates in the wall rocks. These original minerals are described in the section on gangue minerals. (See pp. 71-73.)

SUPERGENE MINERALS

Manganese oxides.—The several manganese oxides, pyrolusite, psilomelane, and wad may be recognized here and there, but generally they form intimate mixtures with one another and with limonite. Their abundance is proportionate to the amount of calcite or manganosiderite originally present in the veins; thus pockets of manganese oxides are particularly common at the Buckhorn mine where manganiferous calcite was an important constituent, and less so at the other mines of the Sylvanite district in which calcite is less abundant. In the Eureka district the manganese oxides are most abundant in those veins containing manganosiderite as a major gangue mineral, and they are particularly prominent as impure limonitic mixtures that inherit the crystalline structure of the original manganosiderite.

The wall rocks of the veins of the Eureka district near and at the surface are stained brown with manganese oxides, and fresher rock from deeper down quickly assumes a brown stain when the rock is thrown on the dump and the manganiferous carbonates in it are oxidized.

ARSENIC

HYPOGENE MINERALS

Arsenopyrite.—Arsenopyrite (mispickel) appears to have been common at the American mine in the Eureka district, to judge from the material in the ore bin and on the dump. It forms small needlelike prismatic crystals having diamond-shaped cross sections. The needles are rarely more than ¼ inch long and generally are much shorter; both pinacoid and dome terminations are present, and cruciform twins were observed. Some crystals are scattered in the wall rock; some are embedded in a cement of sericite that has replaced the residual rock matter; and some are embedded in manganosiderite, sulfides, and calcite that have replaced the sericite and some of the arsenopyrite. (See pls. 17, *C*, *E*, and *F*.) Similar minute crystals replace the wall rocks at the Miss Pickle mine and are embedded in later sphalerite and galena. (See pl. 18, *A*, *B*.) A number of tons of arsenic ore have been shipped from the Miss Pickle mine.

At the Gold Hill mine in the Sylvanite district crusts of arsenopyrite lie along tight joint planes in the aplite dike at one place in the west tunnel (pl. 24), and crystals of arsenopyrite are disseminated in the adjoining rock. Arsenopyrite is by far the most abundant ore mineral at the Creeper tunnels at Sylvanite camp, where it forms replacement pods and kidneys of massive ore as much as 40 or 50 feet in diameter and several feet thick. (See pls. 17, *D*, 26.) A little is likewise disseminated in the wall rock. According to George Blood, operator of the Buckhorn mine in 1935, the assayer reports arsenic in the Buckhorn ore, suggesting that arsenopyrite is present, and a few crystals of mimetite at the Silver Trail tunnel suggest its presence there, too.

Tetrahedrite.—See under copper minerals.

SUPERGENE MINERALS

Copper arsenates.—See under copper minerals.

Mimetite.—See under lead minerals.

Scorodite.—Scorodite, hydrated iron arsenate and the characteristic oxidation product of arsenopyrite, is prominent at the Creeper tunnels in the Sylvanite district and at the Miss Pickle tunnel in the Eureka district. Doubtless it is present in the oxidized parts of the other arsenic-bearing veins as well, particularly at the American mine, though not recognized.

The scorodite is commonly liver brown, amorphous, and limonitelike and because of its association with limonite may be confused with it, but once the scorodite has been recognized, its liver-brown color can be readily distinguished from the various shades of limonite. At the Miss Pickle tunnel the arsenopyrite crystals are pseudomorphically replaced by brown scorodite, but elsewhere at that mine and at the Creeper tunnels some scorodite has spread out into the adjacent rock. At both places, and particularly at the Creeper tunnels, some of the scorodite is a pale-green minutely crystalline material outwardly resembling the dense sericite in which the arsenopyrite at the American mine is embedded.

OTHER ORE MINERALS

ANTIMONY

Stibnite.—Lindgren [70] reported that the American ore contains a little stibnite, but careful search of the ore bin and dumps at the American mine failed to disclose any.

Tetrahedrite.—See under copper minerals.

BISMUTH

Tetradymite.—Flaky tetradymite is the most characteristic ore mineral of the gold veins of the Sylvanite district and is the most prominent of the ore minerals at the Little Mildred mine. It occupies small blebs or pockets in the quartz and calcite and forms veinlets that cut those minerals. The native gold of the veins is intimately associated with tetradymite, and at the Little Mildred mine the tetradymite is intimately intergrown with hessite. (See pl. 15, *F*.) The tetradymite and associated hessite and native gold appear to be the latest minerals of the Sylvanite veins.

In the Eureka district, tetradymite, or even bismuth carbonate stain, was observed only in a 30-foot shaft just south of the southeast corner of the Virginia claim, where flakes of tetradymite may be seen along a stringer of oxidized pyrite and chalcopyrite. Much copper arsenate is present.

Specimens of tetradymite from the Little Mildred mine were sent to the Geological Survey for identification several years ago by one of the residents of the district, and the following analysis is taken from the resulting report, which contains also a mineragraphic description:[71]

Analysis of tetradymite from the Little Mildred mine
[Insoluble deducted]

	Percent		Percent
Te	45.33	Bi	52.90
S	0.71	Fe	0.52
Se	None	Mg	Trace

Recent studies [72] indicate that this mineral is tellurobismuthite (Bi_2Te_3) and not tetradymite (Bi_2Te_2S), but as the mineral from the Little Mildred mine was originally described as tetradymite and is so known among mining men, that name is retained in this report.

Bismutite.—Small pockets of earthy bismutite (a basic bismuth carbonate), as well as apple-green, yellow, and whitish stains, are present near and at the outcrops of the tetradymite-bearing veins.

MOLYBDENUM

Molybdenite is disseminated in the vein walls and forms thin films along rock joints at one place in the Santa Maria tunnel in the Sylvanite district. (See pl. 27.) Threads, blebs, and disseminated grains of molybdenite, associated with pyrite, pyrrhotite, and epidote, are present in sugary calcite and included fragments of wall rock from the bottom of the Faria shaft nearby.

Molybdenite is reported from a contact metamorphic prospect about midway between the Santa Maria tunnel and the Copper Dick mine.

TELLURIUM

See under tetradymite (bismuth telluride) and hessite (silver telluride).

TUNGSTEN

Lindgren's [73] report on the Eureka district states that "some tons of very rich lead-silver ore containing wolframite are stated to have been shipped from a prospect owned by A. C. Young." No evidence of tungsten minerals was noted anywhere in the Little Hatchet Mountains during the present investigation.[73a]

VANADIUM

Light-green to dull olive-green stains and thin crusts of mottramite, a basic vanadate of lead, zinc, and copper of supergene origin, spot the walls of the

[70] Lindgren and others, op. cit. (Prof. Paper 68), p. 336.

[71] Short, M. N., and Henderson, E. P., Tetradymite from Hachita, N. Mex.: Am. Mineralogist, vol. 11, pp. 316–317, 1926.

[72] Frondel, Clifford, Redefinition of tellurobismuthite and vandiestite: Am. Jour. Sci., vol. 238, pp. 880–888, 1940.

[73] Lindgren and others, op. cit. (Prof. Paper 68), p. 336.

[73a] During the strategic mineral investigations of 1941, after this report had been written, G. O. Gates, one of the tungsten geologists of the Geological Survey, at my request examined some of the garnet areas of the Little Hatchet Mountains for scheelite, using an ultraviolet lamp. In the Eureka area he found scheelite only along the string of monzonite porphyry dikes extending from the east end of the Virginia claim to the Copper King mine. The strongest showing is at the shaft where tetradymite is present. (See this page, column one.) The scheelite is in veinlets in both the lime-silicate rock and in the dikes.

In the Sylvanite district Gates found scheelite intergrown with quartz in a 10-inch vein, otherwise typical of the veins of the Sylvanite district, crossing the tongue of metamorphosed Broken Jug limestone northeast of hill 5309 near Livermore Spring.

stope at the Wasp mine in the Eureka district and seem somewhat more prominent on the oxidized dump rock at the Silver Trail tunnel in the Sylvanite district. A reliable field test for this mineral, as well as for oxidized vanadium minerals in general, is that the mineral turns dark brown or momentarily blood red when moistened with a drop of concentrated hydrochloric acid.

GANGUE MINERALS

SILICATES

Actinolite.—Actinolite is one of the presulfide silicate minerals that characterize the veins of the Sylvanite district. Though present in very minor amounts, it is almost universal in its distribution in the district.

The actinolite is the light pearly-green variety called glassy actinolite.[74] It replaces the quartz gangue and forms small tufts and rosettes of slender radiating crystals, which are clustered into small pockets, form small veinlets, or are distributed in isolated spots in the quartz. The largest pocket observed is about 3 inches across; the average length of the actinolite crystals is about 2 millimeters and the maximum length about 1 centimeter. Invariably it is associated with a sugary calcite with which it appears to be contemporaneous. At some places it is intimately associated with chlorite.

The accompanying table gives the optical properties of the glassy actinolite as determined in detail by Miss Jewell Glass of the Geological Survey on specimens from two localities (specimens 1 and 2). Casual determinations by myself of other specimens of glassy actinolite from every place where observed show that all are alike except some from the Copper Dick mine. (See note to analysis 4.) A chemical analysis of the specimen from the Santa Maria tunnel by Charles Milton, of the Geological Survey, gave the following results (the ferric iron in the analysis includes the iron from a little pyrite discovered in the specimen after the analysis had been made):

Analysis of actinolite from the Santa Maria tunnel, Little Hatchet Mountains, N. Mex.

	Percent		Percent
SiO_2	55.52	Na_2O	0.22
Al_2O_3	2.08	K_2O	.07
Fe_2O_3	.31	H_2O	1.04
FeO	7.16	TiO_2	.05
MgO	19.25	MnO	.17
CaO	12.71		
			98.58

Isolated needles of a dark-green actinolite, having somewhat higher indices of refraction and a more intense pleochroism than the glassy variety and more closely allied to pargasite, are distributed in calcite at the lower Creeper tunnel. Dark-green actinolite, which is similar but has variable indices, replaces the garnet and garnet-diopside wall rock at the Little Mildred (Green) and Copper Dick mines. (See pl. 19, *C*.) As viewed in thin section, this wall rock mineral is similar to the blue-green metamorphic amphibole widely distributed in the intrusive rocks and in the intruded Lower Cretaceous volcanics. (See pp. 57-59.) The optical properties of the alteration mineral and that from the Creeper tunnel are included in the accompanying table.

[74] Dana, E. S., A textbook of mineralogy, 3d ed., p. 489, 1922.

Optical properties of actinolite from the Sylvanite district, Little Hatchet Mountains, N. Mex.

	α	β	γ	$\gamma - \alpha$	$Z \wedge C$	2V(—)	Dispersion
1	1.615	1.631	1.643	0.028	12° ±	80°	....
2	1.614	1.630	1.641	.027	13° ±	80°—85°	....
3	1.643	1.660	1.667	.024	18° ±	60° ±	r > v
4	1.639	1.652	1.661	.022	16° ±	60°—65°	....
5	1.625	1.641	1.652	.027	14°	Large	r > v

Pleochroism

	X	Y	Z
1	Nearly colorless to pale yellow.	Light bright green to greenish yellow.	Light blue to blueish green.
2	Pale yellow to colorless.	.........do.........	Do.
3	Light yellow.	Olive green with yellow tint.	Deep blue to deep green.
4	Pale yellow.	Yellowish green to emerald green.	Blueish green.
5	Yellow.	Blue green.	Blue green.

1. Glassy actinolite from the Santa Maria tunnel.
2. Glassy actinolite from the Wake-up-Charlie mine.
3. Dark-green vein actinolite (pargasite) from the Creeper tunnel.
4. Dark-green wall-rock alteration actinolite (pargasite) from the Copper Dick mine. Identical in optical properties with glassy actinolite from same mine.
5. Dark-green wall-rock alteration actinolite from the Little Mildred (Green) mine.

Albite.—Many of the veins of the Sylvanite district are bordered by a halo of white to pinkish albitized rock whose distribution in the district suggests that it is characteristic of the district as a whole. For example, not only is it one of the characteristic features of the tourmaline-gold-tetradymite veins as represented by the Little Mildred, Wake-up-Charlie, and Handcar veins, but also it is typical of the Creeper veins in which arsenopyrite is the predominant ore mineral and in which gold has thus far been found only by assay. Albite is present also at the Copper Dick mine where the ore body was a replacement deposit of chalcopyrite in garnetite. The albite halo has a maximum width of about 2 feet, and in places it stops as sharply against unalbitized rock as if it were a vein filling.

The albite, which is nearly Ab_{100}, is the earliest of the minerals deposited or formed along the veins of the Sylvanite district. It is intimately associated with tourmaline, which in part may be contemporaneous with it; some small veins and stringers and some parts of ore-bearing veins are composed only of tourmaline with albitized walls. (See pl. 18, *C*.) The albitized rocks retain their original textures, but the plagioclase is completely albitized and the mafic minerals completely expelled, and considerable secondary sphene and leucoxene have been liberated. The only original minerals still present are apatite, some orthoclase, and quartz. Because of the expulsion of the iron-bearing minerals, the rock does not rust on weathering but becomes starkly white.

All rocks appear to have been albitized at one place or another in the district—monzonite at the Creeper and Ridgewood tunnels; lamprophyre, monzonite, and garnetite at the Little Mildred mine; quartz monzonite at the Handcar mine; and garnetite at the Copper Dick mine.

Asbestos.—A little asbestos, in streaks not more than an inch in width, lies along a postquartz streak of gouge and breccia in the aplite dike in the west adit at the Gold Hill mine. (See pl. 24.) It is perfectly white and forms thin flexible sheets composed of delicate and flexible silky fibers. Physically, it is identical with the variety of asbestos known as mountain leather. Optically, except in the absence of pleochroism, it seems essentially identical with one of the varieties of chrysotile described by Larsen,[75] but its indices are much below those of any of the chrysotile studied by Selfridge.[76]

Minute granules of calcite are intimately distributed among the asbestos fibers.

Biotite.—Specimens of ore from the dump of the Golden Eagle mine contain streaks of extremely fine-grained black biotite that must be very early in the mineralization sequence, for it is veined and replaced by quartz. The streaks are as much as an inch wide. Comparison of the indices of refraction and birefringence with the chart given by Winchell [77] shows that the biotite is made up of about equal parts of the phlogopite and annite molecules. Its pleochroism ranges from nearly colorless to olive green.

Hill [78] mentions that the Golden Eagle vein is in cholocate-brown monzonite, whose color is due to a brown mica. As observed during the present investigation, the country rock at the Golden Eagle mine is the light-colored facies of the monzonite, but some chocolate-brown monzonite was found on the dump. This rock is thoroughly impregnated with minute flakes of brown mica, but otherwise is identical with the biotite-impregnated rock of the metamorphic stage. Indices of refraction of the brown mica are much below those of the black vein biotite and indicate that the brown mica is phlogopite, containing about 60 percent of the phlogopite-eastonite end of the biotite group.[79] The brown mica is colorless to tan in thin section.

Hill refers the alteration of the monzonite to the "trachyte" dike, the "later latite" of the present report, but the Golden Eagle mine is fully 1,000 feet from the dike, and moreover more detailed study shows that the alteration of the monzonite along the dike as described by Hill is really a widespread feature of metamorphism that considerably antedated the dike injection. It may be that the alteration of the monzonite at the Golden Eagle mine belongs to the metamorphic stage, the biotite developed at that place being less ferriferous than elsewhere, but inasmuch as the brown mica seems confined to the immediate vicinity of the Golden Eagle vein and inasmuch also as the vein itself contains biotite, it is equally probable that the brown phlogopite belongs to the mineralization stage.

A shiny black biotite whose optical properties are close to those of the black mica at the Golden Eagle mine is present in chalcopyrite-magnetite ore at a small prospect along the contact between lamprophyre and porphyritic granite south of Granite Pass. Minute flakes of biotite having similar pleochroism were observed in a thin section of calcite from the Santa Maria tunnel.

Chlorite.—Though present only in very minor amounts, chlorite is one of the characteristic presulfide silicate minerals of the Sylvanite deposits. Commonly it is either embedded in quartz, as flakes, small crystals, and pockets 2 or 3 inches or less across, or forms veinlets cutting the quartz. Some pockets fill original drusy cavities in the quartz. It is characteristically associated with calcite, with which it is in part intergrown and in part cuts as small stringers. At the Silver Trail tunnel, minute well-developed books and groups of books are embedded in the calcite.

The general color of the chlorite is a light pearly green, but at the Silver Trail tunnel the cleavage flakes are a bright epidote green and the crystals themselves are jet black. The average diameter of the flakes seems to lie between 1 and 2 millimeters, but some chlorite is so fine-grained that it appears black in the aggregate. All this chlorite, including that at the Silver Trail tunnel, is optically negative, with indices β and γ ranging from 1.600 to 1.615, and corresponds to Winchells' [80] diabantite group.

The ore at the Copper Dick mine contains slaty, hard black chlorite in crystalline plates fully as broad as the palm of one's hand, and the chlorite seems earlier than the calcite, rather than contemporaneous with it or later as is general in the district. The indices β and γ are close to 1.65, and the mineral corresponds to Winchell's[81] thuringite group.

A second generation of chlorite has been observed in the Sylvanite district at the Gold Hill and Little Mildred mines. This chlorite is deep green and forms minute threads that cut the calcite (pl. 19, *A*, *B*), quartz, and apparently also the sulfides and follow the boundaries between gangue and sulfide minerals. The chlorite at the Gold Hill mine has β about 1.65 whereas that at the Little Mildred mine has β about 1.61.

A fine-grained chlorite occupying about the same place in the mineral sequence as the late generation of the Sylvanite district is moderately abundant in the material on the King dump in the Eureka district. It is later than all else except a late generation of calcite that fills postsulfide faults and fissures; the chlorite itself seems later than that stage of fissuring and to have just preceded the calcite, for globular crusts of it line walls of fissures whose central parts contain the late calcite. It is dark green and extremely fine-grained and tends to form minute velvety black globules on exposed surfaces, the globules themselves being generally less than a millimeter in diameter. Threads of it vein the other minerals, including an earlier generation of calcite that, with the pyritohedral pyrite already described, was the last mineral to be deposited before the fissuring mentioned above. Some pockets and streaks of dense chlorite contain corroded spots of calcite and embedded pyritohedrons of pyrite that leave little doubt that chlorite has selectively replaced the calcite. Most

[75] Larsen, E. S., and Berman, Harry, The microscopic determination of the nonopaque minerals: U. S. Geol. Survey Bull. 848, p. 100, 1934.

[76] Selfridge, G. C., An X-ray and optical investigation of the serpentine minerals: Am. Mineralogist, vol. 21, pp. 463–501, 1936.

[77] Winchell, N. H. and A. N., Elements of optical mineralogy, 2d ed., p. 368, 1927.

[78] Hill, J. M., in Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 341, 342, 1910.

[79] Winchell, N. H. and A. N., op. cit., p. 368.

[80] Winchell, N. H. and A. N., op. cit., p. 376, 1927.

[81] Idem.

of the chlorite pockets contain drusy globule-lined cavities whose shape and distribution suggest the shrinkage cavities of silicified limestone. The velvety chlorite is optically negative, and the value of β is 1.640 or a trifle higher.

Similar fine-grained chlorite was observed on dumps of the Eighth of March vein, and fine-grained globular chlorite accompanies quartz and oxidized chalcopyrite in a shallow pit at the south tip of the specularite area of secs. 2 and 11. Its relation to the chalcopyrite is not evident, but it is grown on quartz crystals and cuts sericitized rock, and so may be analogous to the late chlorite of the King vein.

Epidote.—A little vein epidote was noted at a few prospects in the Sylvanite district, where it is intimately associated with calcite as one of the presulfide silicates.

At the Creeper mine a few indistinct threads of epidote cut and apparently replace the earlier calcite of the vein, and at the Wake-up-Charlie mine a little granular epidote forms a crust on actinolite. Streaks of dull-green, fine-grained epidote seem intergrown or at least very closely associated with calcite at the Golden Eagle mine, and other dull-green epidote, in long, well-formed, needlelike crystals, was seen in the calcite of the Santa Maria vein. Some of the individual crystals at the Santa Maria are more than half an inch long and less than a thirtieth of an inch in diameter. Bright-green epidote, both granular and crystalline, is associated with the calcite in the magnetite-bearing vein of the Faria workings, and the sugary calcite from the molybdenite-bearing vein at the bottom of the main Faria shaft is distinctly traversed by many threads of fine-grained epidote.

Bright-green epidote cuts and impregnates the wall rocks at the Copper Dick mine and forms reaction rims around residual fragments of garnetite as one of the stages leading to the complete replacement of the garnet by calcite, actinolite, magnetite, epidote, and ore minerals. (See pl. 19, *C.*) Long individual crystals, divergent clusters, and small grains of the epidote are embedded in the calcite and in the slaty chlorite of that deposit.

Indices of refraction indicate that the iron content of the vein epidote is about 12 percent or more of Fe_2O_3.[82]

Muscovite and sericite.—A little pearly sericitic mica, in flakes as much as 3 millimeters across and in general sufficiently coarse-grained to be called muscovite, seems widespread in the Sylvanite district. Apparently it is most common at the Gold Hill mine, where it occurs as flakes, small pockets, and streaks ½ inch or less wide in the quartz, which it replaces; as threads cutting the quartz; and as apparently independent pockets and threads in the joints of the adjacent aplite wall rock. Elsewhere flakes and small pockets are associated with tourmaline stringers and more intimately with calcite and chlorite; microscopic examination discloses that the muscovite may be later than the calcite, for threads of it follow contacts between calcite and residual pockets of wall rock, and crystals of muscovite tend to lie along the grain contacts.

Muscovite, in still coarser flakes fully half an inch across, was observed in the Eureka district on the northeast slope of hill 5654 in the Hidalgo volcanics and about 100 feet above the sedimentary member. A zone of crushed rock there about 6 feet wide is thoroughly impregnated with the mica, which also coats the walls of joints for an additional 4 feet or so on each side. Some of the joints are really vein stringers containing limonite and copper stain. The occurrence cannot be traced beyond the narrow drain in which it is exposed.

A compact, massive sericitic mica of a pale green color and extremely fine grain forms the matrix for the needles of arsenopyrite in the American vein. Threads of the mica cross the crystals of arsenopyrite, and it is believed, on the basis of microscopic examination of altered wall rock, that the arsenopyrite was distributed in wall rock that later was replaced by the sericitic mica. The most thoroughly altered monzonite wall rock still recognizable as such consists chiefly of the fine-grained mica, which in part appears to have replaced earlier sericite pseudomorphs of coarser grain.

Small pockets and thin seams, an inch or less in width, of similar compact fine-grained green sericitic mica, identified by C. S. Ross, of the Geological Survey, are present in the specularite-impregnated rock in secs. 2 and 11 southwest of the American mine, and a great volume of the rocks is intensely sericitized.

Orthoclase.—White orthoclase is one of the early minerals of the deposit at the Copper Dick mine. (See pl. 19, *C.*) Cleavage fragments over half an inch in length may be recognized.

Equally coarse-grained white orthoclase is closely associated with vein scapolite (see below) at the Ridgewood mine. Specimens of ore from the dump of the Golden Eagle mine contain white orthoclase in the quartz stringers, as first identified by Hill,[83] but it is strongly masked by quartz and calcite and is difficult to recognize.

Scapolite.—Scapolite, a chlorine-bearing contact-metamorphic silicate similar to plagioclase feldspar in composition and prominent in the metamorphic rocks in the Little Hatchet Mountains, has been observed as a vein mineral at two places in the Sylvanite district.

On the nose of the lamprophyre ridge in the quartz monzonite above Sylvanite, an open cut in lamprophyre exposes a 14-inch vein of white columnar scapolite containing rosettes of black tourmaline and a few specks of oxidized pyrite. Individual slender columns of the scapolite are fully 4 inches long. The mineral is the sodic variety dipyrite, about Ma_{60} or Ma_{65} in composition. The vein is traceable for about 20 feet only.

White scapolite, in divergent and partly vuggy clusters of columnar crystals an inch or less in length, is the most abundant mineral in some of the vein stringers in the monzonite at the Ridgewood mine. The stringers have the usual halo of albite and in addition to the scapolite contain the usual vein assemblage of the Sylvanite district. According to the indices of refraction, $\epsilon = 1.542$ and $\omega = 1.560$, as determined by Miss Glass, of the Geological Survey, the composition of the scapolite is about

[82] Winchell, N. H., and A. N., op. cit., p. 355.

[83] Hill, J. M., op. cit. (U. S. Geol. Survey Prof. Paper 68), pp. 341–342.

Ma_{65}, essentially identical with that of the scapolite in the other vein occurrence and with the scapolite in the metamorphic halo.

Sphene.—Microscopic threads of sphene cut the alteration halos that border the garnetite residuals in the ore of the Copper Dick mine. Characteristic crystals, partly replaced by calcite, were observed in one of the orthoclase stringers.

All the albitized wall rocks of the veins of the Sylvanite district contain a considerable amount of secondary sphene and leucoxene that presumably represent the titanium content of the original ferromagnesian minerals, liberated when those minerals were destroyed during albitization. Granules, pockets, and threads of the leucoxene are scattered throughout the albitized rock, and mixed or intergrown with the leucoxene are recognizable grains of sphene, which also is present at places independent of leucoxene.

Possibly the sphene and leucoxene may be that produced during the metamorphic stage of activity, but the abundance of these minerals in the albite halos, the fact that some leucoxene-sphene stringers cross albite crystals, and the presence of vein sphene at the Copper Dick mine indicate that some leucoxene and sphene belong to the vein-forming stage.

Tourmaline.—Black tourmaline is common in most veins of the Sylvanite district. Though not observed in every vein, its wide distribution in the district suggests that it is probably present at some place or other in all veins. It evidently was deposited immediately after the albite, and typically forms the central part of tourmaline-albite veins (pl. 18, *C*) and fine threads and wider veinlets, as much as several inches across, that cut and replace the albitized rock. (See pl. 17, *D.*) The tourmaline streaks are themselves veined by quartz and calcite, and streaks and isolated crystals of tourmaline are embedded in quartz and calcite where interstitial albitized rock was later replaced by those minerals. (See pl. 18, *D, E.*) Some suggestion of replacement by quartz and calcite can be observed microscopically, but in general the tourmaline appears to have been resistant to replacement by the gangue minerals though apparently later susceptible to replacement by sulfides.

The tourmaline is extremely fine-grained, and the more massive parts are black compact aggregates of interlocking grains commonly only a fraction of a millimeter in length. The largest crystal observed anywhere in the typical veins is only 3 millimeters in length, but rosettes of tourmaline composed of crystals half an inch or more long are present in the scapolite stringer described on p. 72. At the outcrop, the tourmaline seems black, but many crystals in freshly mined material have a brownish cast. In thin section ϵ is colorless and ω is light brown, deep brown, greenish brown, light blue, or deep blue, being variable within single crystals. In thicker grains, immersed in index oils, the color for ϵ is a faint pink. The value of ϵ as determined on tourmaline from the Little Mildred vein is near 1.625 and ω is a little higher than 1.645.

Vermiculite.—Pseudomorphs of vermiculite mica, a hydrous silicate of iron, magnesium, and aluminum, replace the biotite books of an altered monzonite porphyry dike along the tunnel at the turquoise workings at Turquoise Mountain, just southwest of Old Hachita.

The vermiculite books still look like the original biotite crystals, but on being heated they swell greatly into wormlike shapes in the fashion peculiar to vermiculite. The vermiculite appears to represent an intermediate stage in the alteration of the biotite and in the general alteration of the rock to clay minerals by sulfate solutions derived from weathering of the original vein minerals.

OTHER GANGUE MINERALS

Barite.—Barite has been observed at so many places in the Eureka district that it may be assumed to be typical of the district as a whole, even though not noted in some veins and though present in others only as a trace.

It appears to be common in the veins of the Silver Tree area, southwest of the Ringbone Ranch, but has been observed only at isolated places within the main part of the district. In some specimens it veins manganosiderite, and in others on the King dump small plates of barite are veined by calcite and crusted with globules of chlorite; in one specimen a few small plates are embedded in calcite.

In the Sylvanite district, barite is one of the principal minerals in the Santa Maria vein on the Bader property and is present in the string of quartz-pyrite veins north and west of Cottonwood Spring in the same general area, but it is unknown elsewhere in the district. It is massive and coarse-grained at the Santa Maria tunnel, and the chalcopyrite there appears to have been most abundant in association with it. The barite is distinctly veined and replaced by the chalcopyrite and by sugary calcite containing pyritohedrons of pyrite and blebs of chalcopyrite.

Calcite.—Calcite is a typical constituent of both the Sylvanite and Eureka deposits, but in each district it has particular features of crystallinity, composition, and age relations to the other vein minerals. Each district contains two generations of calcite, the later generation of the Sylvanite district corresponding to the earlier generation of the Eureka district.

In the Sylvanite district the earlier generation is by far the more abundant and characteristic. All veins contain it. It belongs to the silicate stage of deposition and was introduced before the main stages of metallization. It is distinctly later than the quartz, contemporaneous with the actinolite, in part contemporaneous and in part earlier than the chlorite, and apparently altogether earlier than the muscovite locally present. With the exception of the arsenopyrite at the Creeper mine and of some pyrite that may be contemporaneous with earlier quartz, it is cleanly veined and in part replaced by all sulfide and other ore minerals. (See pl. 19, *A, B.*)

The earlier generation calcite is variably white, creamy, gray, and pink and ranges from the fine-grained sugary variety usually associated with the actinolite, to a coarser-grained variety, yielding cleavage pieces uncommonly as much as 4 inches on edge, in the more usual vein filling. It all contains manganese and iron, as indicated in the table of analyses below. Microscopic examination of specimens indicates that the brown and black patches and streaks locally common in the calcite are unreplaced residuals of silicated wall rocks.

The later generation of calcite in the Sylvanite district was observed in very minor amount at the Creeper and Santa Maria tunnels in relationships already described on p. 65. This generation, in appearance and particularly in its relations to the sulfides, seems identical with the early generation of calcite of the Eureka district. It is present in all veins of the Eureka district, but is particularly prominent only in the deposits of the Hornet area. It is white and fine- to medium-grained in the average vein and weathers brown because of a small manganese content. In the Hornet area it is much coarser-grained than elsewhere and tends to form curved crystals, to be creamy in color, and to weather yellow with iron oxides instead of brown with manganese oxides. It seems to have been the only gangue mineral in the ore body at the Hornet mine; spheroidal masses of the curved calcite, as much as a foot in diameter, may yet be seen along the walls of the stopes, where they have replaced the limestone wall rock.

In all the deposits of the Eureka district, including those of the Hornet area, the early generation calcite is accompanied by yellow pyritohedral crystals of pyrite, and the presence of such crystals helps in the identification. It was deposited at the extreme end of the sulfide stage. All of it is later than the early sulfides—arsenopyrite, earlier pyrite, sphalerite, and tennantite; some is apparently contemporaneous with galena and chalcopyrite; some, with the accompanying pyritohedral pyrite, is still later than the lead and copper sulfides; and some is later than all sulfides.

The later generation of calcite in the Eureka district was deposited in some postsulfide faults that offset the veins, in related cracks in the ore and walls, and in earlier unfilled openings. Locally, the new calcite is gray, but more generally it is decidedly pink, and it shows an almost invariable tendency to form scalenohedral crystals 2 inches or more in length growing outward from the cavity walls.

Like the calcite of the Sylvanite district, all calcite of the Eureka deposits contains iron and manganese, but in varying amounts. The following table gives the iron and manganese content for four specimens, two from the Sylvanite district, and two from the Eureka district. Evidently the calcite from the Sylvanite veins is relatively high in iron and low in manganese, whereas that from the Eureka district contains, on the average, nearly equal amounts of iron and manganese.

Analyses of calcite from the Little Hatchet Mountains, New Mexico

[F. C. M. Smithson, New Mexico School of Mines, analyst]

	Sylvanite district			Eureka district		
	1	2	Average	3	4	Average
$FeCO_3$ (percent)	2.67	1.83	2.25	1.08	0.84	0.96
$MnCO_3$ (percent)	.31	.41	.36	.48	1.21	.85

1. Pink calcite, Gold Hill mine.
2. Gray calcite, Silver Trail tunnel.
3. Hornet mine.
4. Pink scalenohedral calcite, King 400 mine.

Calcite stained black by manganese oxides and associated with calcite of the lamellar variety accompanies quartz in the fault and related fissures cutting the Tertiary volcanic rocks west of the Skunk Ranch.

Rhombohedral crystals of supergene calcite, sparkling, glassy, and colorless to white, the largest crystal about 1/4 inch on edge, were observed underground at the Santa Maria tunnel and more abundantly in specimens on the Santa Maria and Faria dumps. The calcite rhombs are deposited on oxidized vein matter. Long divergent crystals of supergene calcite, colorless to yellow and brown and of the variety that in finer grain forms Mexican onyx, are abundant at the Last Chance prospect, between the Hornet and American mines.

Fluorite.—A vein of calcite, quartz, and purple fluorite extends northwestward through the monzonite between the south tip of the Jowell vein and the Copper Dick fault in the Sylvanite district.

Fluorite has been found at no other place in the Little Hatchet Mountains.

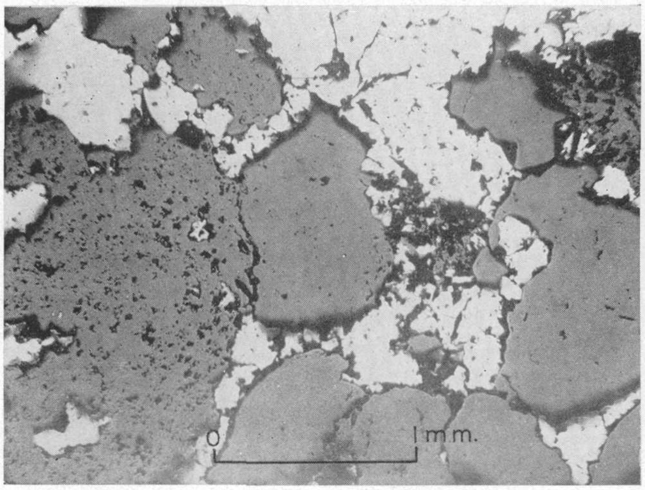
Quartz.—Quartz is the commonest mineral in the veins of the Sylvanite district, though it is not abundant, for the veins themselves are not wide. Stringers of it ranging from a small fraction of an inch in width to an uncommon maximum of 2½ feet cut the earlier albite-tourmaline parts of the veins and the original wall rocks, and at some places those stringers, barren or nearly barren of ore minerals, constitute the vein.

In appearance the quartz is the type characteristic of deep-seated, high-temperature (hypothermal) deposits—massive, coarse-grained and generally white, but verging in one direction on a glassy variety and less commonly in the other direction on dull-white "bull quartz"; at the Gold Hill mine it is more persistently glassy than elsewhere. A few small druses in the quartz are still open, and others are filled with actinolite, chlorite, or calcite, all of which also cut and replace the quartz. Close scrutiny of almost any specimen is likely to reveal spots of either chlorite or actinolite. Irregular cavities several inches across and containing a honeycomb of unoriented quartz crystals were observed in the oxidized parts of the Buckhorn mine, and the random arrangement of the crystals suggests either that they had replaced an earlier host, which has since been removed, or had been supported by some other mineral contemporaneously deposited, perhaps pyrite, also since removed.

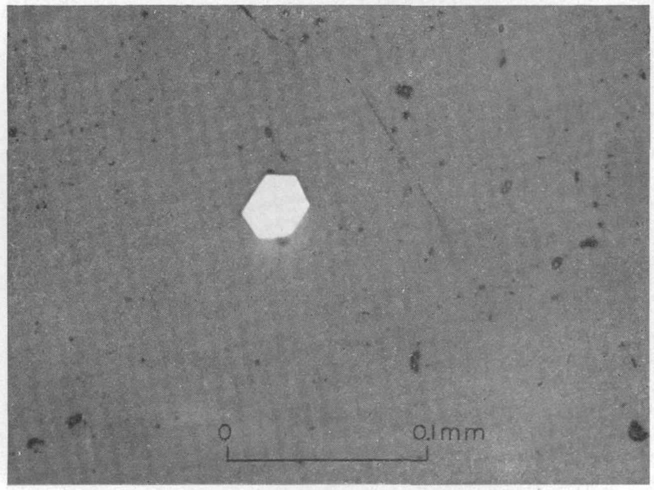
The only gangue minerals known to be earlier than quartz are albite, tourmaline, sphene, and the biotite found at the Golden Eagle prospect. The only ore mineral that is earlier is arsenopyrite, which is distinctly veined by quartz at the Creeper tunnels. At a few places, particularly at the Buckhorn mine, small crystals and streaks or pockets of pyrite are distributed in the quartz in such a way as to suggest that they and the quartz were deposited together, and at the Clemmie mine the quartz stringers contain minute and perfect crystals of pyrrhotite that presumably are contemporaneous with the quartz. (See pl. 17, *B*.)

Here and there in the Sylvanite veins it is apparent that quartz has replaced earlier material, and on the dump of the Baders' Silver Trail tunnel a trace of jasperoid was observed.

Quartz is a common but not an invariable constituent of the veins of the Eureka district, nor is it



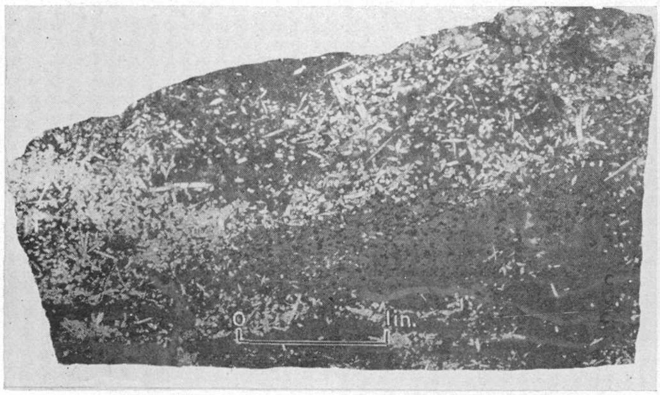
A



B

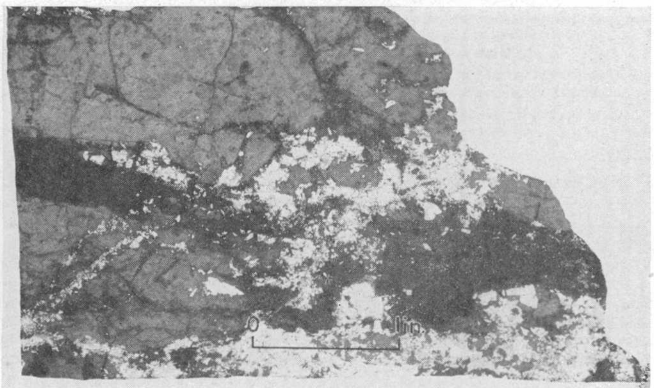
PHOTOMICROGRAPHS OF POLISHED SPECIMENS OF ORE FROM THE CLEMMIE MINE.

A, Pyrrhotite (white) interstitial to the quartz grains (gray) of a coarse-grained quartzite; *B*, Microscopic hexagonal crystal of pyrrhotite in vein quartz



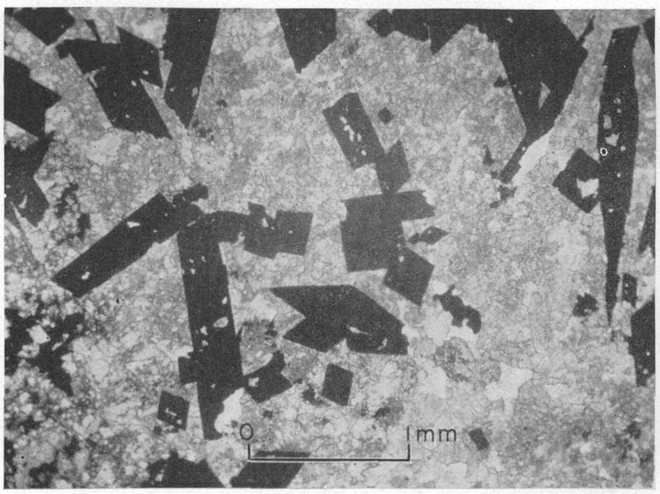
C. POLISHED HAND SPECIMEN OF ARSENOPYRITE-BEARING ORE FROM THE AMERICAN MINE, EUREKA DISTRICT.

Shows characteristic size, shape, and distribution of the arsenopyrite crystals (white diamond-shaped and needle-shaped crystals). Matrix includes sericite, calcite, oxidized manganosiderite, altered rock, and traces of galena and chalcopyrite. c, Late stringers of calcite. Small black spots are pits from which sericite has been gouged.

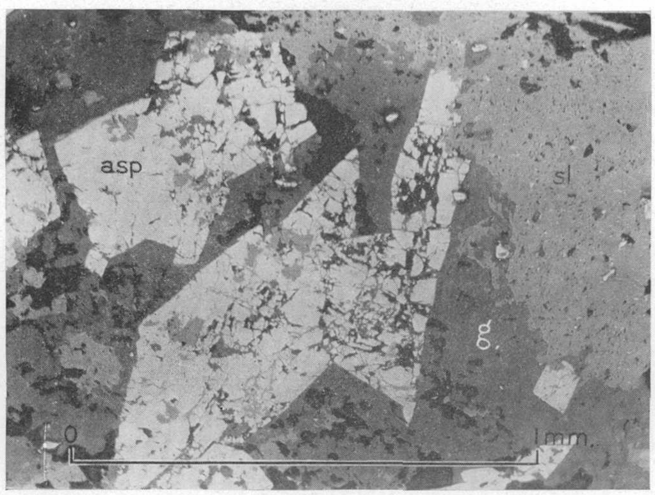


D. POLISHED HAND SPECIMEN OF ORE FROM THE CREEPER MINE, SYLVANITE DISTRICT.

Shows albitized monzonite (spotted gray with igneous texture) veined by tourmaline (dark gray to black); both monzonite and tourmaline veined and replaced by arsenopyrite (white).



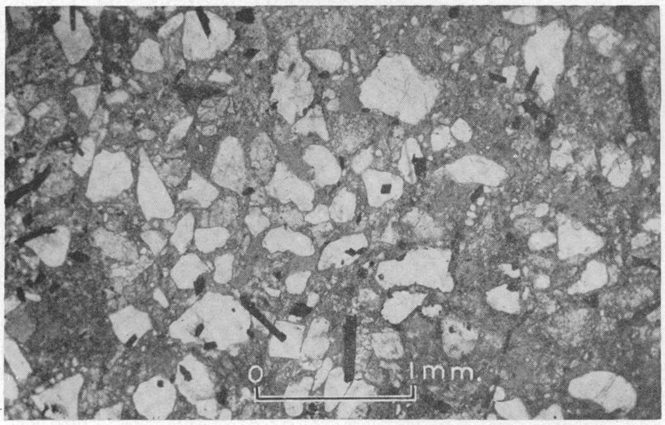
E



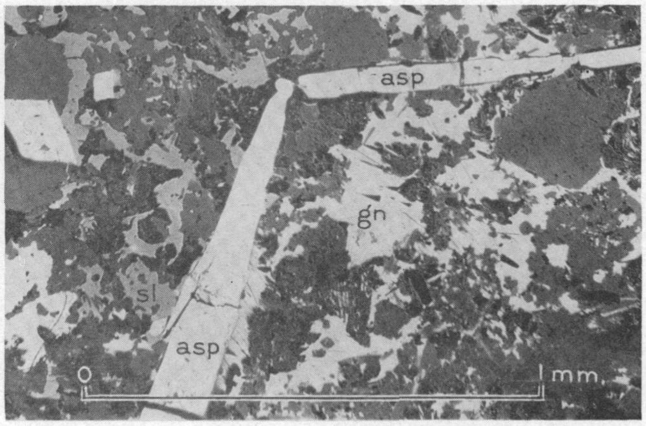
F

PHOTOMICROGRAPHS OF ORE FROM THE AMERICAN MINE.

E, Thin section showing crystals of arsenopyrite (black) in a cement of manganosiderite and calcite. To judge from other specimens, the carbonate has completely replaced earlier massive sericite. Plain transmitted light. *F*, Polished specimen of fragment from specimen illustrated in *E*. Shattered crystals of arsenopyrite (asp) corroded by sphalerite (sl) and by gangue (g, largely manganosiderite). Black areas are holes in the section.



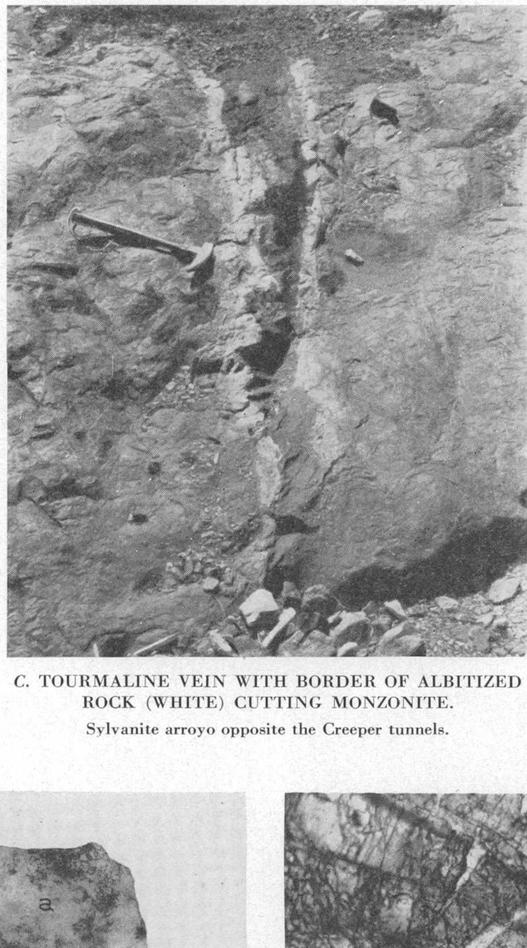
A



B

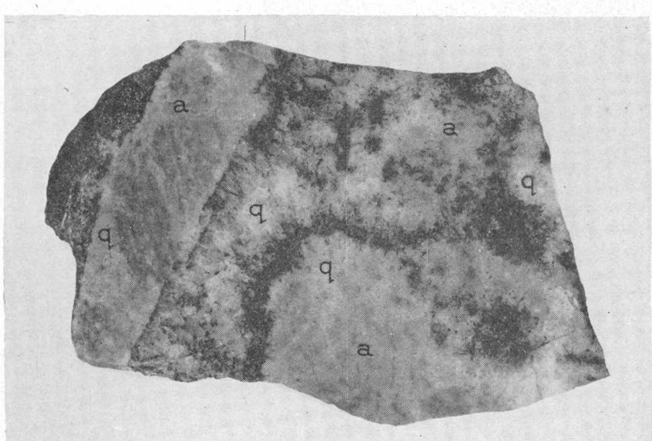
PHOTOMICROGRAPHS OF SPECIMENS FROM THE MISS PICKLE TUNNEL.

A, Thin section of limy, shaly sandstone containing crystals of arsenopyrite (black). Plain transmitted light. *B*, Polished specimen of sandstone partly replaced by arsenopyrite (asp) and by later sphalerite (sl) and galena (gn).



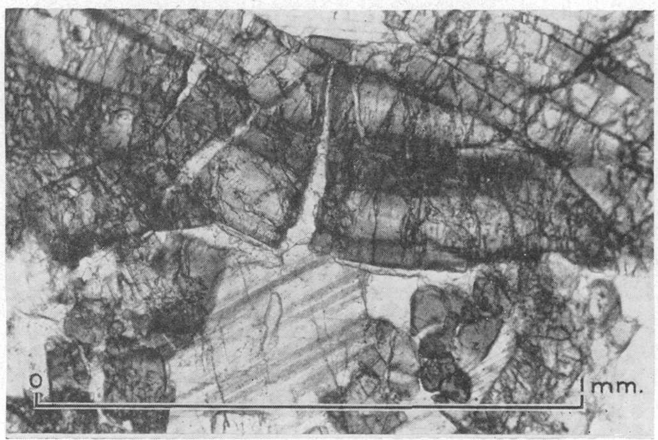
C. TOURMALINE VEIN WITH BORDER OF ALBITIZED ROCK (WHITE) CUTTING MONZONITE.

Sylvanite arroyo opposite the Creeper tunnels.



D. POLISHED HAND SPECIMEN OF VEIN MATTER FROM THE WAKE-UP-CHARLIE MINE.

a, Silicified, albitized rock; q, quartz; black areas and needles, tourmaline.

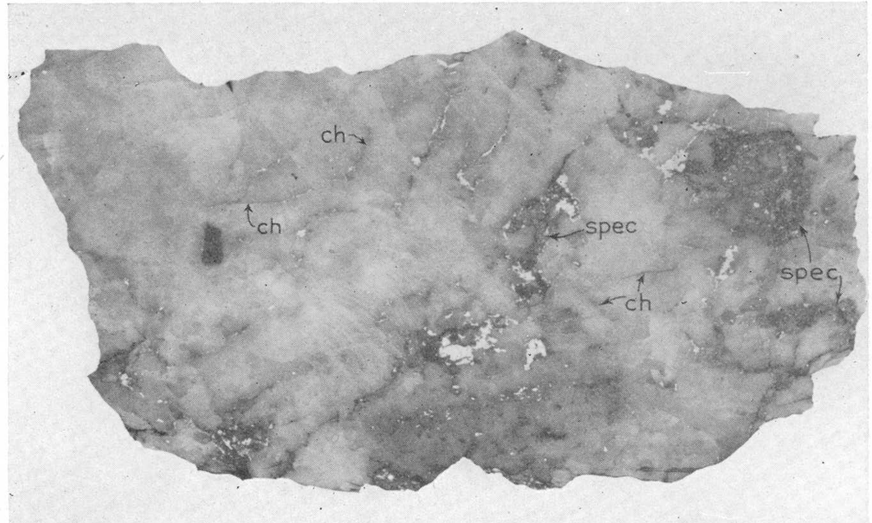


E. PHOTOMICROGRAPH OF THIN SECTION OF VEIN MATTER FROM THE GREEN (LITTLE MILDRED) MINE.

Shows broken crystals of tourmaline veined and cemented by calcite. Plain transmitted light.

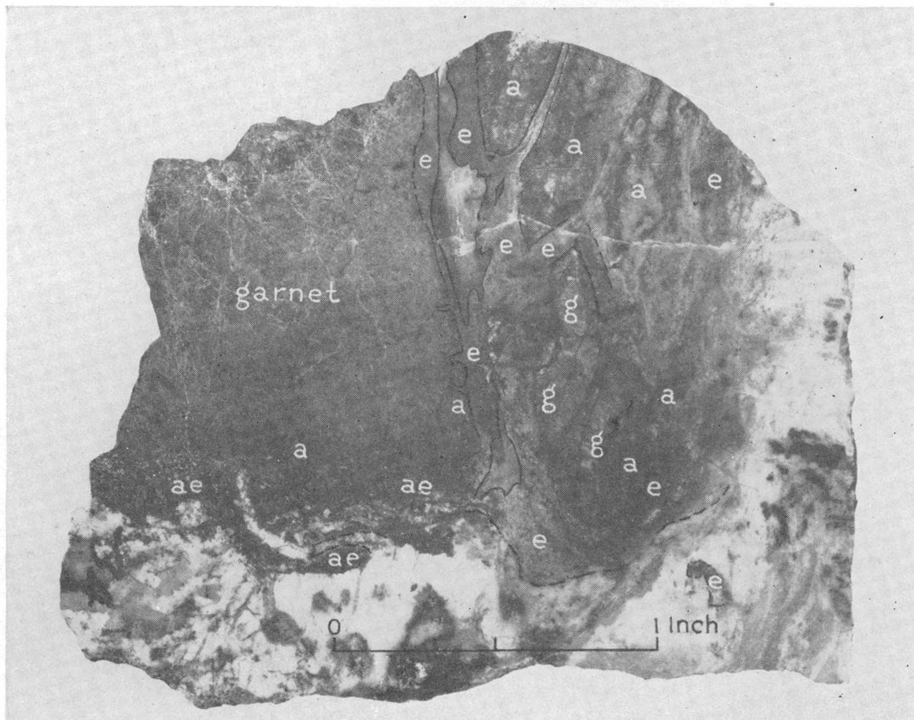
A. POLISHED HAND SPECIMEN OF ORE FROM THE GOLD HILL MINE.

Shows calcite (white background) veined and replaced by ore minerals and by the second generation of chlorite.



B. SAME SPECIMEN AS *A* BUT BY REFLECTED LIGHT IN ORDER TO DIFFERENTIATE THE SEVERAL MINERALS.

White blebs and threads, chalcopyrite and very minor amounts of sphalerite and galena; spotted gray (spec), specularite; gray parts of the sulfide threads, as at places marked ch, chlorite.



C. POLISHED SPECIMEN OF ORE FROM THE COPPER DICK MINE.

Shows the several stages in the replacement of the garnet wall rock by minerals of the ore assemblage. g, Garnet; a, actinolite, calcite, and magnetite; e, epidote; ae, transition zone between a and e. White outer zone at bottom and right side of specimen contains orthoclase, albite, quartz, calcite, some few spots of minerals of the inner zones, and isolated grains of chalcopyrite. The discontinuous stringer extending through the center of the specimen is mineralogically similar to the outer zone, though containing chiefly calcite and a few grains of chalcopyrite.

so prominent as in the Sylvanite district. A little of it looks glassy, but all is more or less milky.

At the American mine, one of the most productive mines of the Eureka district, the only quartz I saw, either in the few workings open to study or on the dump, were some thin milky threads cutting altered wall rock. In the other principal veins, the National, King, and Howard, a little milky quartz is mixed with sulfides in the ore shoots, and comby stringers cut the walls. Irregular veins cut the abundant manganosiderite gangue, but in the same specimens some manganosiderite fills drusy pockets in the quartz or fills the space between the comb walls. Microscopic study of the parts containing quartz and sulfides discloses that most of the quartz is earlier than the sulfides, with the possible exception of the pale variety of pyrite, but there also is a little quartz in some calcite stringers cutting the sulfides. Quartz is the predominant vein filling beyond the limits of the ore shoots, but the stringers are narrow and the total amount of quartz present is small.

Some of the vein stringers at the King mine have cherty jasperoid walls, but the widest band of jasperoid observed, on the dump, was hardly more than 2 inches wide. Fragments of silicified rock in ore were seen on the dump of the Silver King mine, and other dump specimens indicate some silicification of the walls. The fissures in the footwall side of the Hornet ore body have jasperoid walls 6 inches or less wide, and here and there a little silicified rock can be seen along the walls of the old stopes.

Silicification was intense along spurs from the Miss Pickle fault at the specularite deposits in secs. 2 and 11 southwest of the American mine, and large volumes of rock were completely replaced. Veins of quartz, accompanied by specularite and in part dull white and resembling the white quartz of the Sylvanite veins, in part slightly milky, cut the specularitized and silicified rocks. A shallow prospect near the Miss Pickle mine discloses "bull quartz" in the main spur fault leading to the specularitized area.

Several veins of barren white vuggy quartz in silicified walls extend southward from the Miss Pickle fault in secs. 29 and 33.

Quartz of the type characteristic of epithermal deposits in Tertiary volcanic rocks was found locally along the fault cutting the Tertiary rocks west of the Skunk Ranch. Part is fine-grained and glassy, part forms combs of minute crystals on the walls of earlier lamellar calcite embedded in the fine-grained quartz, and part is a colloform-banded variety, fine-grained to chalcedonic.

Small crystals of supergene quartz, glassy within but in places coated with blue chalcedony, cover the surfaces of limonite boxwork in some specimens from the Santa Maria tunnel. Other specimens on the Santa Maria dump are composed of minute crystals of supergene quartz clouded with brown limonite and cemented with still more limonite, the whole very much resembling jasper.

Manganosiderite.—A manganese-iron carbonate is common and prominent in all veins and stringers of the main part of the Eureka district and is present also in the outlying veins in the Silver Trail area near the Ringbone Ranch. It appears to be absent from the veins in the Hornet area, however, the southernmost point at which it has been found being in the vicinity of the Young prospect, just south of the Ohio fault and about a third of the way between the American and Hornet mines. It seems most abundant in and near the ore shoots.

As thus far exposed in the shallow workings of the Eureka district, the manganosiderite is almost invariably oxidized to a shiny black material that looks surprisingly like an iron-bearing sphalerite, and it has been so mistaken by visitors to the district. The freshest material seen resembles pearly brown siderite, but the lower index of refraction measured on the cleavage is about 1.72, indicating that the original carbonate was sufficiently rich in the $MnCO_3$ molecule to be called manganosiderite.

With the exception of arsenopyrite, which it replaces in the American ore, the manganosiderite is earlier than the ore minerals. It likewise replaces the fine-grained sericitic mica in the arsenopyrite-sericite associations in the American ore. In many specimens it is cut by threads of quartz, but in the King vein manganosiderite occupies the space between the comby walls of quartz stringers.

An ash-gray to brown carbonate, having high indices and extreme absorption and presumably the same as the manganosiderite of the vein filling, is a common alteration mineral with calcite and sericite in the immediate walls of the veins. In this association it appears to be replaced by sericite.

ORDER OF DEPOSITION

The order in which the minerals of the ore deposits were introduced—their paragenesis—is of special interest in considering the mineralogic relationships between the Eureka and Sylvanite districts, which in turn are pertinent in evaluating the future productivity of the Little Hatchet Mountains. The paragenesis also throws light on the great diversity of the deposits.

The full succession, mineral by mineral, cannot be determined, because there are too few places where it can be studied adequately. Figure 11, though inaccurate in detail, shows the sequence as fully as information permits and helps to present the general picture. It is strictly qualitative, the lines representing the

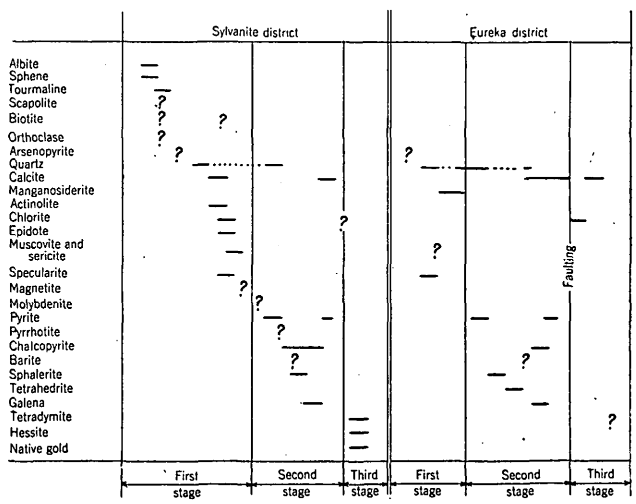


FIGURE 11.—Diagram showing mineral succession in the Sylvanite and Eureka mining districts.

different minerals being drawn long or short as may be necessary to show the known detail. Minerals whose position in the sequence is uncertain are shown with a question mark; for example, molybdenite is known to be later than calcite at one place, but nothing is known of its relation to the other post-calcite minerals. There are many degrees of uncertainty, however, and the use of a solid line for a few of the minerals indicates only a feeling of moderate assurance as to their proper position. Asbestos and fluorite are left out of the diagram entirely.

Though the details of succession are not certain for all minerals, the general course of deposition is clear, and stages characterized by particular mineral associations can be recognized. In each district there are three analogous stages. Those in the Sylvanite district are as follows:

(1) The silicate stage, which may be separated into two substages: the albite-tourmaline stage and a quartz-calcite stage containing the rest of the silicates. The albite-tourmaline stage apparently includes some of the sphene in the albite halo, the biotite in the Golden Eagle vein, and perhaps scapolite and orthoclase. The minerals of the quartz-calcite stage commonly form veins and stringers cutting the albite-tourmaline rock. Quartz is everywhere distinctly the earliest mineral of this group. Next is the earlier calcite (the high iron-low manganese variety), accompanied by actinolite and later by chlorite and epidote, though the chlorite and epidote continue beyond the calcite phase. The muscovite seems altogether post-calcite. The little specularite and magnetite apparently belong to this stage. Arsenopyrite is shown as probably intermediate between the two silicate substages, because in the Creeper tunnels, the only place showing a distinct age relation, the arsenopyrite replaces albite-tourmaline rock but is veined by the white subglassy variety of quartz.

(2) The sulfide stage, which includes a little quartz, the jasperoid and barite of the Bader area, all the sulfides except arsenopyrite (see paragraph above), and the second generation of calcite, which was deposited at the close of the sulfide stage along with the latest chalcopyrite and galena and the second generation of pyrite (the yellow pyritohedral variety). The second generation of chlorite may belong to this stage; it is later than the sulfides, but I have no hint as to its relation to the minerals of the next stage.

(3) The telluride-gold stage, which closes the sequence. The minerals of this stage include, in order of abundance, only tetradymite, native gold, and hessite, all apparently contemporaneous.

In the Eureka district the three stages are as follows:

(1) The presulfide stage. Belonging to this stage are arsenopyrite, muscovite, sericite, white quartz resembling that of the Sylvanite district, specularite, and manganosiderite. Many of the details of age relations are uncertain because few of these minerals have been found together, but as a group they suggest the late phase of stage 1 of the Sylvanite district, the position of the first-generation calcite of the Sylvanite veins being occupied roughly by the manganosiderite.

(2) The sulfide stage. The details of this stage are fairly clear, the sulfides following a well-defined sequence: early pyrite (the pale cubic variety), sphalerite, tetrahedrite, chalcopyrite and galena, and the second generation of pyrite (the yellow pyritohedral variety). The only uncertainty among the sulfides concerns the first-generation pyrite, some of which may be contemporaneous with the arsenopyrite. The gangue minerals of the sulfide stage are an early milky quartz, barite, and calcite, the calcite accompanying the post-tetrahedrite sulfide and continuing uncontaminated beyond the sulfide phase.

(3) The postsulfide stage. This, the last stage, includes primarily the velvety globular chlorite of the King vein and the scalenohedral calcite, both of which were deposited in postvein faults and fissures. The tetradymite, found in the Eureka district only in one prospect shaft, may belong to this stage.

LATE CRETACEOUS OR EARLY TERTIARY DEPOSITS

DEPOSITS OF THE SYLVANITE DISTRICT

TYPES OF DEPOSITS

If classified according to the predominant ore mineral, a wide variety of deposits may be recognized in the Sylvanite district, and if considered also in light of their shape or mode of formation, a still wider variety appears. There are literally almost as many types as there are prospects, for among the dozen most prominent mines and prospects there are 8 types of deposits, and to these may be added 2 other types of no commercial appeal. The 10 types include:

1. Disseminated pyrite in monzonite.
2. A chalcopyrite replacement deposit in garnetite at the Copper Dick Mine.
3. A pyrrhotite replacement deposit in quartzite at the Clemmie mine.
4. A chalcopyrite-tourmaline vein deposit at the Buckhorn mine.
5. Arsenopyrite-tourmaline veins at the Creeper tunnels.
6. Tetradymite-native gold veins, represented chiefly by the Gold Hill, Little Mildred, Wake-up-Charlie, Pearl, and some of the Handcar workings.
7. A chalcopyrite-barite deposit at the Santa Maria tunnel.
8. A galena vein at the Silver Trail tunnel.
9. Quartz-pyrite and quartz-pyrite-chalcopyrite stringers such as the Broken Jug prospect.
10. A fluorite-calcite-quartz vein, unnamed.

Type 1 is the pyritized monzonite near Cottonwood Spring believed to be related to the metamorphic stage of activity described on p. 58. Types 1 and 10 are the two of no commercial appeal, and neither requires further comment.

The other 8 types are logically considered together, for all have much the same mineral assemblage, and their great diversity indicates only that at times during the mineralization sequence some veins or parts of veins received more material than others. No crowding of the different stages of deposition that make up the full sequence can be seen; rather, the minerals form an orderly succession from start to finish, with times when only a single mineral seems to have been deposited. Consequently, any vein that was most open or most receptive to deposition at a particular stage of the sequence is characterized by the mineral or minerals peculiar to that stage. The Little Mildred vein best typifies the average vein of the district, though not every mineral has been recognized in it, and a brief description of it is given here to illustrate the general type from which the subtypes deviate. At the Little Mildred mine an albite halo two feet or less wide borders the vein fissure, and stringers of tourmaline, locally very prominent, cut and replace the albitized rock. The albite-tourmaline rock in turn is cut by veins of quartz a foot or less thick containing small pockets of actinolite and chlorite. Calcite is present locally. The sulfides include small amounts of pyrite and chalcopyrite and traces of sphalerite, galena, and, locally, arsenopyrite. Threads of tetradymite, native gold, and hessite vein the other minerals, particularly the quartz and calcite.

Regardless of local concentrations of one or another of the several sulfides, the average sulfide content is only a small percentage of the total vein filling, and although eight subtypes of ore deposits may be present from one point of view, as classified above, from the commercial aspect all but the Copper Dick (type 2) are gold deposits. The Copper Dick, not strictly a vein deposit, is the only one in which a sulfide was valued for itself alone, and with an estimated output of about 4,000 tons it has been the most productive in the Sylvanite district; the Santa Maria and Silver Trail deposits (types 7 and 8) have been prospected for copper and lead, respectively, but at neither place has the shoot been developed to productive size. At all other places, including the Buckhorn mine (type 4), the metal sought was the native gold brought in during the last stage of deposition.

The general mineral assemblage of these deposits, as summarized in the discussion on the order of deposition, p. 73, includes minerals ranging from those characteristic of the highest temperatures of deposition (those of the silicate stage) to those characteristic of comparatively low temperatures (the tellurides) and indicates a general cooling down from original hypothermal conditions. The presence of vein scapolite of a composition identical with that in the contact-metamorphic halo suggests that the upper limit of the temperature range was near the temperature boundary between hypothermal and pyrometasomatic deposits, placed by Lindgren[84] at about 600° C. The lowest temperature may have been as low as 150°C, for Borchert[85] claims that hessite, one of the tellurides of the district, forms only between 150° and 184°C, though Borchert's figures have yet to be verified. Thus those veins that contain the full assemblage have passed through almost the entire hydrothermal range of temperatures. The depth of formation was perhaps well over 10,000 feet. (See p. 47.)

WALL-ROCK ALTERATION

Aside from the albite halo developed along most veins of the district, the effects of wall-rock alteration by the vein-forming solutions are vague. Where the veins lie in the metamorphic rocks the garnet and diopside beyond the albite border are slightly replaced by actinolite, and the rock in general is somewhat more strongly replaced by calcite and is variably pyritized. This alteration seems most intense at the Copper Dick mine and nearby prospects, which are primarily replacement deposits and in which the actinolite and calcite are accompanied by epidote, chlorite, and magnetite.

Where the veins lie in the igneous rocks, alteration beyond the albite halo is expressed perhaps entirely by impregnation with pyrite and a little calcite, which seem a little more abundant in the vein walls than in the country rock in general. Some ferromagnesian minerals are replaced by actinolite, and a trace of sericite may be present, but these seem hardly more common than elsewhere in the igneous rocks. The brown biotite in the wall rock at the Golden Eagle mine is likely the result of alteration by vein-forming solutions.

There seems to have been a little jasperoidal silicification of wall rock at the Silver Trail tunnel, in keeping with the moderate-temperature galena deposit there, and perhaps also in the Jowell vein.

DISTRIBUTION AND STRUCTURAL FEATURES

Plate 12 shows all veins of the Sylvanite district mappable on this scale, some prospects of historical or mineralogical interest on veins too small to be shown without exaggeration, and the principal prospects not of the vein type. The deposits are so few that it is difficult to generalize about their distribution, but all those mapped are confined to the stock or its metamorphic halo. The most distant prospect, the Clemmie, is only about a mile from the stock. The unmapped prospect holes scattered here and there emphasize this spatial relationship. The four minor prospects of the Granite Pass country are similarly situated with respect to the Granite Pass stock.

Not only are the veins few, but they are short and for the most part tight. The Handcar vein is mapped as a single vein nearly half a mile long, but it is really made up of several overlapping members. The Buckhorn vein, by far the strongest as exposed underground, has been traced on the surface for about 1,500 feet, but the ore shoot seems to be less than 100 feet long. The Little Mildred vein has been traced for nearly 1,500 feet, the Jowell vein for about 1,000 feet, and the Gold Hill vein with certainty for about 800 feet, but all others are less than 300 feet in length. The Wake-up-Charlie vein, whose discovery was the immediate cause of the Sylvanite boom, is traceable only for 175 feet or so.

Most of the veins seem to strike eastward, but others strike northeastward, northward, or northwestward. The dip is generally steep, 70° or more, and may be to either side. In detail some veins are lodes with stringers and some are better-defined fissures; at the Gold Hill mine the minerals lie along closely spaced joints. The veins pinch and swell abruptly and erratically, ranging in width from mere joints to a rare maximum of 15 feet, but they are more commonly tight and narrow than otherwise. The estimated average width is less than 1 foot.

Selvages of gouge and breccia are present here and there, some apparently pre-ore, some obviously post-ore. Transverse post-ore faults can be recognized in

[84] Lindgren, Waldemar, Succession of minerals and temperatures of formation in ore deposits of magmatic affiliations: Am. Inst. Min. Met. Eng. Tech. Pub. 713, pp. 10–11, 1936.
[85] Borchert, H., Neue Beobachtungen an Tellurerzen: Neues Jahrbuch, Beilage-Band 69–A, pp. 460–477, 1935.

some mines, but generally the offset is insignificant. However, post-ore faulting caused real trouble at the Santa Maria tunnel, where spurs from the Copper Dick fault have segmented and badly distorted the vein, and further exploration may show troublesome post-ore faulting at the Copper Dick and Silver Trail mines as well.

Most veins, in fact so many that it is typical of the district, lie along lamprophyre dikes, as does also the replacement deposit at the Copper Dick mine. Most dikes are short, and therefore the longer veins may not everywhere border a lamprophyre dike, but almost invariably a lamprophyre dike forms the wall at some place or other. Along the shorter veins the dikes are fissured like the other country rock, but along the stronger ones they tend to be schistose, presumably because of the biotite in them. The Gold Hill vein lies within an aplite dike, which is of the same age as the lamprophyres, and this mildly emphasizes the general relationship.

Outcrops are inconspicuous as a rule. The sulfide content is ordinarily too small to yield prominent gossans, and though quartz is the most abundant mineral, yet the veins are so narrow and the quartz in such fine stringers that it fails to support the outcrops above the general surface.

DEPOSITS OF THE EUREKA DISTRICT

TYPES OF DEPOSITS

The Eureka district shows the same wide diversity among its deposits as the Sylvanite district, and for the same apparent reasons. The full classification, based chiefly on mineralogy but in part on form and method of formation, is as follows:

1. Disseminated pyrite in monzonite.
2. Quartz-specularite deposits.
3. Limestone-replacement deposits of lead and zinc.
4. Arsenopyrite-lead-zinc veins—with or without manganosiderite.
5. Manganosiderite-galena veins.
6. Manganosiderite-tetrahedrite-galena veins.
7. Quartz-pyrite and quartz-pyrite-chalcopyrite veins.

Type 1 is the pyritized sodic phase of the monzonite, already described and discussed, and needs no further mention. In the following pages, then, only the quartz-specularite and the several varieties of sulfide deposits are considered, the sulfide deposits being described as a group, for, as in the Sylvanite district, all are variations from a common type.

QUARTZ-SPECULARITE DEPOSITS

In the southwest corner of sec. 2 and the adjacent corner of sec. 11, T. 28 S., R. 16 W., on the east slope of hill 5758, where the diorite sill and andesite breccia bed in the Howells Ridge formation are bent into a local anticline, a large volume of rock is impregnated with specularite. In the early days this deposit appears to have been optimistically considered as a source of iron ore for the lead smelter at the Hornet mine, a mile and a half to the east.

The specularite area and the altered rock around it occupy about a tenth of a square mile. Diorite, andesite breccia, and some of the sediments are involved, and at some places alteration is so complete that the original rock is indeterminable. Most conspicuous are two broad, high cliffs of silicified rock, 1,500 to 2,000 feet long, that parallel the bedding and largely wall off between them the altered area. Silicification of the upper wall, which is fully 150 feet wide, appears to have been localized by a bedding-plane fault between the diorite sill and the andesite breccia layer. The lower silicified strip, 1,000 feet down the hill, occupies one of the fault prongs near the southeastern end of the hanging-wall spur of the Miss Pickle fault. Other short members of the fault pattern also are silicified. (See pl. 12.)

Sericitization seems to be the most general feature of the mineralized area. The sericitized rock merges outward into unaltered material and inward, toward the center of the altered country, into a mottled, creamy to blueish-black rock. The creamy rock has been homogeneously sericitized and partly silicified, and the black is the specularitized rock; both are cut by stringers of quartz and specularite, 2 inches or less thick. The creamy rock in particular is crisscrossed by threadlike black veins of specularite, and as these become wider and more abundant the creamy rock grades into the black. Most of the slope between the two silicified ribs is the black rock, interbanded with streaks originally impregnated with pyrite instead of specularite and now strongly impregnated with jarosite. The banding is roughly parallel to the quartz ribs and seems veinlike. All the rock contains faint sporadic stains of azurite, and at the old stage road near the east edge of the area the dump of a prospect pit at the volcanic breccia layer contains quartz-chalcopyrite-chlorite vein matter.

Similar mineralized rocks crop out in sec. 34 to the northwest, where a vein follows the base of the sedimentary layer of the Hidalgo volcanics for nearly a mile, from the north slope of hill 5654 southeastward past the diorite sill. The sedimentary layer is largely silicified, and the vein and silicified rock differ from the specularitized country described above only in having a little less specularite and a little more copper stain.

SULFIDE DEPOSITS

CAUSES OF MINERALOGIC VARIATIONS

Broadly speaking, the deposits of the Eureka district are veins of mixed sulfides in a manganosiderite gangue. Galena and sphalerite are most abundant among the sulfides, arsenopyrite and tetrahedrite are common locally, and chalcopyrite is sparse. Pyrite, of two generations, seems present everywhere, and minor amounts of specularite are present here and there over most of the area. Tetradymite was found in one prospect hole. Minor gangue minerals are calcite, milky quartz, and some barite.

The deposits are primarily mesothermal, that is, formed at intermediate temperatures. The wide distribution of specularite indicates that moderately higher temperatures prevailed at an early stage, but to the extent that the spatial relation, as now known, of specularite mineralization to areas of old volcanic rocks (see p. 65) may be true and significant, there may have been a chemical effect of wall rock on mineralogy. The arsenopyrite at the American and Miss Pickle mines (type 4) evidently indicates the uppermost extent of underlying more intense hypothermal (high-temperature) conditions; perhaps the distinctive shape of the arsenopyrite crystals has some significance with respect to the probable temperature of formation, but unfortunately the conditions controlling the various forms of arsenopyrite have never been investigated as they have for some other minerals. Calcite is one of those other minerals, and the scalenohedral, "dog-tooth," variety, the youngest mineral with the possible exception of the one occurrence of tetradymite, indicates a general cooling down to low-temperature conditions [86] at the close of the mineralization period. The tetradymite, which presumably forms at the same general temperature as the tellurides of gold and silver, may indicate that the temperature during its stage of deposition was roughly about 175° C.[87]

In addition to this decrease of temperature with time, the temperature may also have varied from place to place, as suggested by the distribution of the manganosiderite. This mineral seems distinctly most abundant in the veins near the Old Hachita stock, that is, in the American, National, Howard, and King veins, but fades out south of the Ohio fault (see pls. 5 and 12) ; and in the limestone replacement deposits of the Hornet area (type 3) there is no manganosiderite at all, the gangue being almost entirely iron- and manganese-bearing calcite.

The Miss Pickle vein also escaped the manganosiderite stage, but perhaps because it was not permeable in the stage between the arsenopyrite and the later sulfides rather than because of a temperature zoning. Variations in permeability with time and place probably account also for the other mineralogic variations in the deposits. The tetrahedrite, for example, which characterizes the deposits of type 6, occupies a distinct place in the mineral sequence, and presumably the three shoots in which it has been found, the King 400, Silver King, and Howard (?), were the only parts of what is now observable that were open during the tetrahedrite stage. There are a few distinct veins of type 7, the best known of which are the Copper King and Stiles, but most commonly type 7 is represented by the narrow parts of the ore-bearing veins between the shoots, as best exposed by the prospect holes along the King and Howard veins and nearby stringers.

WALL-ROCK ALTERATION

Wall-rock alteration in the Eureka deposits is weak for a mesothermal type of deposit and would perhaps escape casual observation entirely were it not for the common brown weathering stain on the rock fragments of all dumps in the main part of the area, produced by the oxidation of manganosiderite in them.

Immediately next to the vein walls, except at a few silicified spots, the rocks are completely converted to manganosiderite, sericite, and calcite accompanied by a few grains of pyrite and some hydrothermal quartz, but the original rock texture is still recognizable. This complete alteration is well exposed only at the King 400 mine, where it was found to reach not more than a couple of feet from the vein. A specimen of diorite from a point 8 feet from the vein contains no manganosiderite and only a little more calcite and sericite than the diorite elsewhere, and a specimen of limestone from within a foot of the vein still retains much of its original composition. Here and there the veins and vein stringers have a silicified selvage of jasperoid, but its width is only a matter of inches.

[86] Schaller, W. T., The crystal cavities of the New Jersey zeolite region: U. S. Geol. Survey Bull. 832, p. 47, 1932.

[87] Borchert, H., Neue Beobachtungen an Tellurerzen: Neues Jahrbuch, Beilage-Band 69-A, pp. 460–477, 1935.

DISTRIBUTION AND STRUCTURAL FEATURES

The principal prospects of the Eureka area are clustered around the monzonite facies of the Old Hachita stock, and with the exception of the replacement deposits of the Hornet area are eastward-trending veins related to the Ohio-National-Old Hachita fault group. Only three noteworthy ore shoots have been found, all within the lower *Orbitolina*-bearing zone of the Broken Jug limestone and thus at about the same horizon as the monzonite. They are the Hornet shoot, which has yielded 15,000 or 20,000 tons; the American shoot, which has yielded about 25,000 tons; and the King 400 shoot, which has yielded 10,000 to 15,000 tons.

If the outlying prospects also are considered, the deposits may be said to lie within a band, 1 to 1½ miles wide, that extends northwestward from Old Hachita to the west edge of the range, where it includes the veins of the Silver Tree area, and southward from Old Hachita through the Hornet country to the Copper Dick fault, thus including some scattered prospects between the Hornet mine and the Miss Pickle fault and a few stringers in the hills between Howells Wells and the Copper Dick fault. The specularite deposits of secs. 2 and 11 are outside this band at present, but they fall within it if the fault block in which they lie is restored to its original position. The ore band, it will be observed, encompasses the full exposure of the Old Hachita stock and follows the general trend of the formations, a condition presumably reflecting the stock's sill-like form.

The veins are too few and too poorly exposed to warrant a conclusive generalization about their size. The American vein, which, as noted above, contains the largest shoot thus far discovered in the district, can be traced with assurance for only 1,000 feet. The King vein, containing the King 400 shoot, is traceable for about 2,000 feet but is really a zone of several discontinuous or overlapping members rather than a single vein fissure, and over most of its length it is hardly more than a crushed zone less than a foot wide containing stringers of vein matter whose combined thickness does not exceed 4 inches. The Howard vein, traceable for about 2,500 feet, is similar to the King. The National vein is much longer and more persistent than any of the others, but perhaps the prefault fissures, those of the vein-forming stage, were no stronger than the other veins.

The stopes at the King 400 mine range from about 1 to 9 feet in width and are about 3½ feet wide on the average, and those at the American mine seem to have similar widths.

The veins of the area show a decided tendency to follow the monzonite porphyry dikes, and a typical relationship is illustrated by the King vein. (See pl. 22.) Throughout the heart of the district, around Old Hachita, a dike can be found along the wall of nearly every prospect hole. Both dikes and vein stringers along the King vein zone lie along the axis of a mild transverse syncline in the sedimentary rocks, so that the vein is roughly at right angles to the bedding. The situation recalls the relation between veins and transverse folds at Kennecott, Alaska,[88] and the similarity is heightened by the fact that the King 400 shoot appears to rest upon a bedding-plane fault. (See p. 89.) The shoot occupies a zone of brecciation apparently produced by the hanging wall of the vein fissure sagging down against and along the bedding-plane fault.

ZONAL RELATIONS BETWEEN THE EUREKA AND SYLVANITE DISTRICTS

The section on structure (see pp. 47-48) expresses the opinion that the Eureka and Sylvanite districts were at one time continuous, one above the other, in the manner shown in part 2 of plate 13. That conclusion was said to be supported by certain features of the ore deposits that suggest a zonal relation between the two districts; these features are here presented in detail.

As indicated in the individual descriptions of the Sylvanite and Eureka districts, the Sylvanite deposits are hypothermal whereas those at Eureka are mesothermal. In view of the structural evidence of original continuity of the two districts, that is suggestive, and its significance is emphasized by detailed comparisons of mineralogy and paragenesis. These comparisons apply not only to the small quantities of hypothermal minerals in the Eureka deposits and of mesothermal minerals in the Sylvanite deposits but also to the "two-generation" minerals—chlorite, calcite, and pyrite. For example, arsenopyrite is present only locally in the Eureka district, but is somewhat more abundant and widespread in the Sylvanite district; the Eureka district also contains in one area a little muscovite and glassy hypothermal quartz, both of which are among the minerals that characterize the first or silicate stage of the Sylvanite ores. Specularite, a mineral suggestive of mildly high temperature, is present in both districts but is a little more general at Eureka than at Sylvanite. Sphalerite and galena, on the contrary, are characteristic and abundant in the Eureka district but are sparse and only locally recognizable in the Sylvanite district. The slight replacement of the wall rock by jasper at the Silver Trail and Jowell veins in the Sylvanite district contrasts with the more general, even though meager, alteration of this type in the Eureka district.

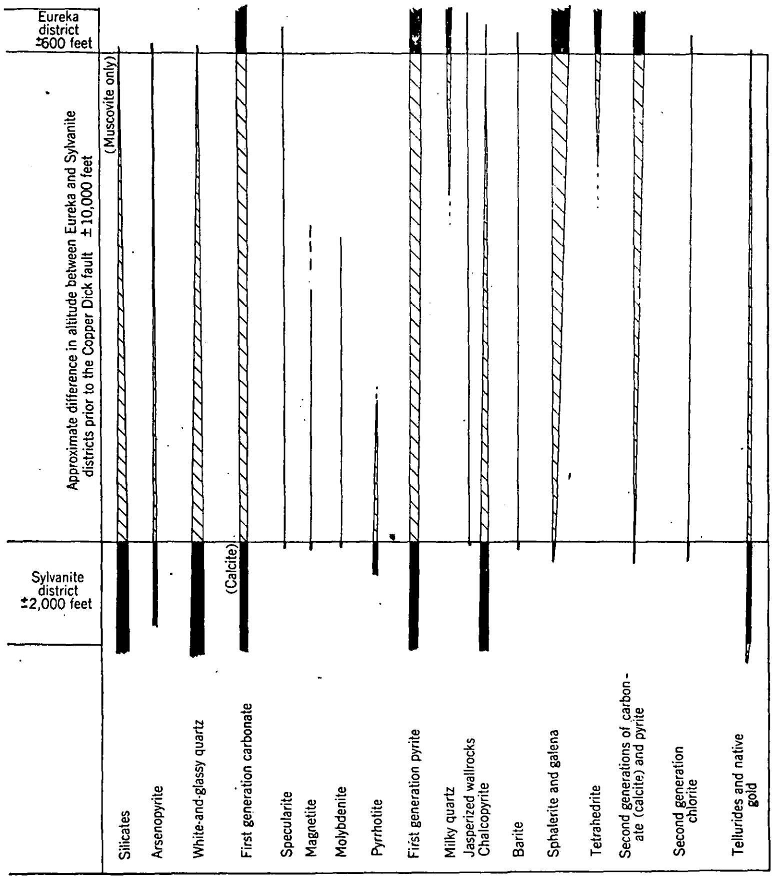


FIGURE 12.—Diagram showing inferred original vertical zonal relations between the Eureka and Sylvanite districts. Vertical distance ascribed to each district indicates range in which the deposits are exposed by topography and mining operations; vertical distance between the two districts is scaled from part 2 of plate 13. Length of solid lines indicates relative general distribution, and width of lines indicates importance.

The first-generation calcite of the Sylvanite district, an iron and manganese-bearing variety, is represented at Eureka by an iron-manganese carbonate, manganosiderite. Both districts contain the two generations of pyrite in the same positions in the mineralogic sequence, the distinctive properties of the pyrite of each generation being such that the two

[88] Bateman, A. M., and McLaughlin, D. H., Geology of the ore deposits of Kennecott, Alaska: Econ. Geology, vol. 15, pp. 1-80, 1920. Lasky, S. G., Transverse faults at Kennecott and their relation to the main fault system: Am. Inst. Min. Met. Eng. Trans. Yearbook, pp. 303-317, 1929.

varieties have the significance of different mineral species. Moreover, in both districts the second-generation pyrite is intimately associated with calcite in identical relations. The chlorite of the Eureka ores occupies the same position in the sequence as the second-generation chlorite of the Sylvanite ores. In general, it may be said that if the Eureka half of the paragenesis diagram (fig. 11) is superimposed on the Sylvanite half, many of the known details closely match, impressively so if the Eureka sequence is compacted by omission of the tetrahedrite.

Figure 12 summarizes these mineralogic details graphically and correlates them with structure, on the assumption that the original continuity of the two districts has been demonstrated. The relations thus shown are interpreted as the natural interfingering of mesothermal and hypothermal zones—the muscovite, arsenopyrite, and white glassy quartz of the Eureka district indicating the uppermost reaches of the Sylvanite hypothermal zone; and the sphalerite, galena, and second-generation calcite, pyrite, and chlorite in the Sylvanite veins, as well as the faint local jasperization, indicating the lowermost reaches of the Eureka mesothermal zone. The strongest mineralization of the mesothermal type in the Sylvanite district is in the Santa Maria-Silver Trail area, and this strengthens the interpretation, for that area was originally closer to the Eureka country than any other part of the Sylvanite district, as may be seen from plate 13.

Incidentally, this postulated original continuity of the Sylvanite and Eureka districts clarifies one otherwise puzzling feature, namely, the close similarity of the Eureka veins to the stringery veins of the Sylvanite district rather than to the continuous and well-defined veins of most mesothermal deposits. The cover over what is now the Sylvanite stock must have exceeded 10,000 feet (see p. 49), and as the Sylvanite-Old Hachita stock was a flat-lying sill-like mass,the Eureka part also must have been under considerable cover, so that fissures suggestive of deep zones are to be expected in the Eureka district.

The alternative that the two districts are separate centers of intrusion and mineralization has already been considered (p. 48) and discarded for structural reasons. Mineralogic reasons also oppose it; it would, indeed, be a coincidence for separate centers to counterfeit the interfingering of mesothermal and hypothermal zones in such detail, even to the "two-generation" minerals. Considering both structural and mineralogic evidence, the alternative has little appeal. (See also pp. 31-32.)

The kind of ores that may accompany the unexposed parts of the Sylvanite-Old Hachita stock between the two districts—in the Miss Pickle-Copper Dick fault block—may be deduced from the zonal picture. They should contain the minerals of the central block of figure 12 and hence should be primarily silver-bearing base-metal ores containing also tellurides, native gold, and an appreciable amount of arsenopyrite. The gangue presumably should include silicates, lessening northward, an early generation of calcite that gives way northward to manganosiderite, a late generation of calcite at the close of the sulfide stage, two generations of quartz and pyrite, and a little barite.

ORIGIN OF THE LATE CRETACEOUS OR EARLY TERTIARY DEPOSITS

The genetic relation of many ore deposits to igneous activity is almost universally accepted by geologists, but so direct a connection between the ore deposits and the associated intrusive rocks as in the Little Hatchet Mountains is rarely seen. This direct relationship is indicated by an apparent transition from the pyrogenetic stage of activity to metamorphism and then to vein deposition, with sodium as a characteristic element throughout the sequence. The facts and conclusions concerning the various stages of activity have been discussed in the appropriate sections on petrology, metamorphism, and ore deposits and are here summarized.

(1) Soda-rich volatiles became concentrated in the tip of the Sylvanite-Old Hachita stock at a late pyrogenetic stage. (See pp. 31-32.)

(2) Even disregarding the albite there, the metamorphic halo contains much more sodic scapolite than could have been supplied by the soda of the original sedimentary rocks. As the concentration of soda both during the late pyrogenetic stage and during contact metamorphism apparently began before consolidation of the monzonite was complete (see p. 58), and as scapolite was one of the minerals produced in that early stage, the great amount of soda in the metamorphic halo is interpreted as a genetic link between metamorphism and the part of the igneous body now exposed.

(3) The augite and hornblende of the stock rocks were converted by the internal alteration or endomorphism into a distinctive blue-green amphibole, and

(4) A similar amphibole was formed in the igneous rocks of the halo, testifying to the activity of similar solutions. Like testimony is given by the albite in those rocks.

(5) The stock rocks in general show two types of internal alteration. Both types are imposed upon the hybrid monzonite-quartz monzonite in the contact zone of the quartz monzonite above Sylvanite camp, where there seems to be a complete transition from the magmatic stage of the quartz monzonite to the latest stage of alteration by solutions from the quartz monzonite. (See p. 59.)

(6) A striking parallelism in their products, particularly with respect to the development of sodium minerals, strongly implies the continuity of the metamorphic and vein-forming stages. One of these minerals is albite, which is the earliest and one of the most abundant minerals of the Sylvanite veins. Another is sodic scapolite identical in composition with that in the metamorphic halo. The veins contain also a blue-green actinolite apparently identical with that of both endomorphic and exomorphic origin mentioned in paragraphs 3 and 4; traces of biotite, some like the pale endomorphic biotite; traces of sphene, both an exomorphic and endomorphic mineral in the igneous rocks; green epidote, which is prominent in the hybrid monzonite-quartz monzonite halo at Sylvanite (see 5, above) and in the Lower Cretaceous volcanics and is a widespread exomorphic and endomorphic mineral in general; and chlorite and muscovite, analogous to the chlorite and sericite

widespread in the stock rocks. Metamorphism and vein deposition are thus thought to have been parts of the same process, the very solutions that produced the metamorphism beginning to deposit vein matter when directed into the newly opened vein fissures.

It has been stated (pp. 57, 77) that the widespread sericitic alteration of the intrusive rocks is not nearly so strong as in many other mining districts and that the sericitic alteration of the wall rocks along the Eureka veins is unusually weak. Recent work by Fenner [89] in Yellowstone Park suggests a reason for this, assuming that his conclusions may be applied to the deeper-seated conditions of the Little Hatchet Mountains. Fenner [90] says:

> Then, if our deductions are correct, we perceive that the potassium that is so important in substitution processes in the feldspars is not derived (except, perhaps, in small degree) from the igneous body but from carbonate attack upon feldspars of the roof rock at a lower level than the bore hole attained. In short, the potassium is picked up at lower levels by one process and is deposited at higher levels by another. The surprising thing (not dependent upon theory or inference) is that in the upper levels substitution of potassium for sodium goes on until the waters are so depleted of potassium and enriched in sodium that the ratio of the two becomes 1:34 [as contrasted with a ratio of near 1:10 in the magmatic emanations]. This, however, is established with almost as much certainty as if the experiment were performed in the laboratory.

The great quantities of soda expelled from the monzonite in the Little Hatchet Mountains during or shortly after the pyrogenetic stage, and fixed as scapolite and albite in the metamorphic halo, may have prevented as extensive early sodic replacement as otherwise might have occurred. According to Fenner's work, it is by means of this sodic replacement that potash is thrown into the hydrothermal solutions, and the faintness of later sericitic alteration may be a result of the lack of potash so derived.

Similar reasoning may explain the apparent weakness of ore deposition in general in the Little Hatchet Mountains. It is, of course, possible that the parent source did not have much ore material to contribute, but it seems more probable that the ore was dissipated in the many cubic miles of stock rocks and bordering sediments between and beyond what are now the Eureka and Sylvanite horizons. The gently-dipping sill-like attitude of the Sylvanite-Old Hachita stock presumably would have inhibited a rapid rise of the ore-bearing solutions, and they probably escaped from the stock all along its length of more than 7 miles in their slow rise toward the extreme tip. Perhaps the escape of large quantities of emanations even during the pyrogenetic stage indicates that the solutions found it easier to leave the stock than is usually true, but at any rate it seems reasonable to infer that the ore-bearing solutions became scattered before they had opportunity to accumulate in the concentration necessary to form rich and large ore deposits.

MINERALIZATION RELATED TO THE MIOCENE (?) VOLCANIC ROCKS

Mineralization belonging to the Miocene (?) epoch is indicated by the sericite-pyrite alteration of the felsite and earlier latite dikes, by somewhat fainter sericitic alteration of the later latite dikes and of the latite flows of the Skunk Ranch area, and by vein stringers in the pyroclastic rocks. The vein stringers have been observed only along and near the northward-trending fault cutting the volcanic breccias in sec. 7 at the west edge of the range; the filling in them is the quartz-lamellar calcite aggregate so characteristic of many precious metal veins in Tertiary volcanic rocks,[91] accompanied by black calcite similar to that characteristic of some other Tertiary veins,[92] but no trace of metallization has been found.

The mineralization of this period was trivial, but its existence seems important in the history and correlation of ore deposition in southwestern New Mexico. The position of the Miocene (?) stages of mineralization in the igneous and mineralization sequence and a comparison of this sequence with that in other districts nearby has been given on page 38 and in figure 4. The quartz-lamellar calcite-black calcite stage is presumably the same as that which produced the silver-bearing lead deposit of the Red Hill (Gillespie) district in the Animas range across Playas Valley, the highly productive silver-gold deposits of the Mogollon district [93] northwest of Santa Rita, and the productive manganese deposits in the Little Florida Mountains about 10 miles southeast of Deming.[94]

PLACER DEPOSITS

A little placer ground between Livermore and Cottonwood Springs in the Sylvanite district occasionally receives attention from visiting engineers, but the only placer operations in the district in 1937, and for a number of years preceding, aside from the activity of individuals who search the smallest draws for nuggets washed free after each rain, were the seasonal one-man activities of A. E. Bader on the gravel that covers the low ridges west of the Silver Trail tunnel. Every rainfall washes some of the loose gravel down into the shallow draws and rain rills and partly concentrates the gold. This material is collected and further concentrated in dry washers, and the concentrate is panned to remove the large amount of heavy garnet and magnetite sand.

The gravel is the "high alluvium" of this report, and the gold in it was derived from the eroded outcrops of the telluride-native gold veins of the Sylvanite district. The search for nuggets is carried on in the monzonite pediment area between Cottonwood Spring and the Copper Dick fault; some of the gold found in that area may have been liberated by current erosion, but most of it presumably is the relatively small amount left behind during removal of the high alluvium.

The gold particles range from those recoverable only by panning to nuggets weighing as much as an ounce. Nuggets about a tenth of an ounce in weight seem fairly common. Some are still attached to particles of quartz and many others have the rough irregular appearance of having just been liberated

[89] Fenner, C. N., Bore-hole investigations in Yellowstone Park: Jour. Geol., vol. 44, pt. 2, pp. 225–315, 1936.
[90] Fenner, C. N., op. cit., pp. 300–301.

[91] Lindgren, Waldemar, Mineral deposits, 4th ed., pp. 446–450, 1933.
[92] Hewett, D. F., and Pardee, J. T., Manganese in western hydrothermal ore deposits, in Ore deposits of the western States (Lindgren volume), pp. 680—681, Am. Inst. Min. Met. Eng., 1933.
[93] Ferguson, H. G., Geology and ore deposits of the Mogollon mining district, N. Mex.: U. S. Geol. Survey Bull. 787, 1927.
[94] Lasky, S. G., Manganese deposits in the Little Florida Mountains, N. Mex.: U. S. Geol. Survey Bull. 922–C, 1940.

from the original matrix. The fineness of the gold is described in the pages on mineralogy.

TURQUOISE DEPOSITS

The Eureka district was many years ago one of the four major turquoise-producing districts in New Mexico, whose stones have been noted for their quality. The Eureka deposits, which appear to have been worked long before the coming of white men to New Mexico, were rediscovered about 1885 and operated intermittently for about 25 years. Records of production are lacking, but the value of the stones produced must have been comparatively small, to judge from the figures given by Talmage and Wootton [95] for the production of all gems and precious stones throughout the State.

The deposits were visited by D. B. Sterrett [96] in 1909, during the time of greatest activity, and extracts from his excellent report follow:

LITTLE HACHITA MOUNTAINS

The turquoise claims in the Little Hachita Mountains, about 6 miles west of Hachita, in Grant County, have several owners. According to Sterling Burwell, an old resident of the Little Hachita Mountains, the first work done on the turquoise deposits of this region was by Con Ryan and himself between 1885 and 1888. This work was done for gold, as Con Ryan supposed that the ancient workings and dumps in the region were gold mines of the Aztecs or early Spaniards. Turquoise was found, and four claims for this mineral were then taken up by Harry Wood, who soon sold out to eastern purchasers. Archie Young then located all the ancient workings. Assessment work was kept up on a few of these claims only, and in June, 1908, George W. Robinson relocated four of the best claims, in which M. W. Porterfield was given a half interest for financial assistance; these claims were operated during 1909, the first turquoise mining in the region for several years. Other claims are now owned by the American Turquoise Company, of New York, by M. M. Crocker, of Lordsburg, by the Mary Posey Mining Company, of San Antonio, Tex., and by R. S. Chamberlain.

For a few years from 1880 on there was a lively mining camp in this part of the Little Hatchet Mountains, and a silver smelter was built about a mile east of the turquoise deposits. It is said that a little turquoise was found in some of the silver mines of this region. Turquoise is reported to have been worked several years ago by Nick Rascom at Silver Night, about 20 miles to the southwest of the present mines.[97] This work was on old dumps, the remains of some of the old Aztec workings, which are numerous in the Little Hachita Mountains. Around one of these were a large number of stone hammers of crude workmanship. A thin section for microscopic study from one of the hammers shows it to be an andesitic breccia or tuff. The hammer is greenish gray and is very tough; the material for it was probably obtained near the locality where it was used.[98]

* * * The claims are located [near Old Hachita] in a semibasin country open on the east side of the mountains * * *. The country rock of the region consists of a series of interbedded sedimentary, volcanic, and intrusive rocks. * * * A large area of the basin is occupied by trachyte, andesite, and probably monzonite, especially in the northern half. * * * Large areas of the trachyte are so decomposed that its original nature is uncertain.[99] The turquoise deposits are associated with the altered trachyte and probably with altered andesite. In one of the mines a dike of altered porphyry, probably monzonite,[1] was encountered. * * *

Robinson and Porterfield mines.—The claims owned by George W. Robinson and M. W. Porterfield are the Azure, along the top of Turquoise Mountain; the Cameo, nearly one mile north of west of the northeast end of Turquoise Mountain; the Galilee, three-fifths of a mile southwest of Turquoise Mountain; the Aztec, 1½ miles west of south of Turquoise Mountain.

There have been two sets of workings on the Azure claim, one at the northeast end of Turquoise Mountain and the other near the middle of the hill on the top.[2] At the northeast end there were the remains of ancient Aztec workings, mostly filled in, and the prospects of the first white miners. Recent work consists of a tunnel about 160 feet long with a crosscut and stopes connecting with an open cut on the surface. The tunnel was driven in southwest from the northeast end of the hill, and near the end a crosscut was run to the southeast connecting with stopes to surface work above. This drift also encountered Aztec workings, mostly filled in with rubbish, and workings of later people. either Spaniards or early miners during the eighties. This latter excavation consisted of a drift about 35 feet below the surface with the old entrance completely filled with rubbish. This rubbish was either purposely filled in the exit by the early miners to conceal the deposit or has slipped in by the breaking down of the walls. The presence of a small rusted tin can in the bottom of the hidden tunnel and round drill holes suggests a later period of mining than that of the early Spaniards. The open cuts at the surface above were made by former miners and followed the Aztec workings.

The turquoise occurs near the contact of a very fine-grained trachyte and a porphyry, probably monzonite, both badly decomposed. The contact of these two rocks extends northeast and is quite irregular. The turquoise is found mostly in the trachyte, especially where the latter has been fractured and stained with iron oxides. The rock has been badly broken, and the turquoise fills the fractures with irregularly shaped seams ranging from a very small fraction of an inch to half an inch in thickness. These seams branch and cross one another and open abruptly out from small size to large size. Where the rock is very badly fractured the joints are sometimes all filled with turquoise forming masses of matrix of good size. The matrix is harder where strongly stained with yellow and brown iron oxide, and in combination with the fine color of part of the turquoise it makes beautiful matrix gems. The turquoise ranges in color from dark skyblue to pale blue and greenish blue. The dark blue and the greenish blue are very hard; the pale blue variety is rather soft. The principal yield from this claim is in matrix turquoise with some good cameo material.

At the southwest end of the Azure claim two open cuts were made in a northwest direction. These cuts were in trachyte rock and exposed seams of turquoise having a northeast strike. Other veinlets of turquoise outcrop along the ridge nearby, associated with limonite stains. Some very hard turquoise with a fine pure blue color was found in the seams in heavily iron-stained rock.

On the Cameo claim a shaft has been dug 40 feet deep and drifts with stopes run from it in a northeast-southwest direction. These drifts and stopes were made on a prominent veinlet of turquoise which strikes northeast with a vertical dip at the surface and inclines at about 75° NW. from a depth of 20 feet to the bottom. The inclosing rock is a yellowish-gray altered trachyte. On the hill above is a massive outcrop of hard, dark andesite. In the bottom of the shaft the best turquoise has been found in a band of rock 7 feet wide lying between two prominent joints or veinlets with a northeast strike and a high northwest dip. Other seams of turquoise occur in varying positions, some lying nearly horizontal and others striking northwest. It is said the best turquoise has been found at points where some of these wide seams cross the main veinlets. The turquoise occurs principally in veinlets and seams, the largest half an inch thick. These veinlets are hard and firmly attached to the wall rock, which is sufficiently hard to serve as a matrix, and some of the turquoise is cut into cameos with it as a base. The wall rock of the seams is yellowish gray to brownish in color. The best turquoise has a good pure blue color, locally passing to greenish blue. This

[95] Talmage, S. B., and Wootton, T. P., The nonmetallic mineral resources of New Mexico and their economic features: New Mexico School of Mines, State Bur. Mines and Mineral Resources Bull. 12, pp. 86–90, 1937.

[96] Sterrett, D. B., Gems and precious stones: U. S. Geol. Survey Mineral Resources for 1909, pt. 2, pp. 791–795, 1911.

[97] This would place the Silver Night workings in the Animas Range, across Playas Valley. (S.G.L.)

[98] Presumably a piece of breccia from the Hidalgo volcanics. (S.G.L.)

[99] Sterrett's "trachyte" is the sodic facies of the monzonite at Old Hachita; his "andesite" is the formation called Hidalgo volcanics in this report; and his "monzonite" evidently includes the diorite sills. (S.G.L.)

[1] One of the common monzonite porphyry dikes of the Eureka district. (S.G.L.)

[2] These workings are on members of the National vein zone. (S.G.L.)

deposit was originally worked by the Aztecs and remains of their work with their stone hammers are still to be seen near the present openings.

The work on the Galilee claim consists of a large shaft or a small irregularly-shaped pit about 20 feet deep.[3] The rock formation is altered trachyte of fine grain and strongly stained with iron oxides. The turquoise occurs in two main veinlets or seams and in a few smaller less pronounced ones. The veinlets are fracture zones strongly stained with limonite, having turquoise in spots or in small rounded grains distributed throughout.

The Aztec claim is on the northeast slope of the southwest side of the basin about 500 feet below the rim. There were Aztec workings on this deposit, and a tunnel was run under them by Harry Wood. Some stoping was done in this tunnel. Mr. Robinson has made a new opening above Harry Wood's tunnel and to the south of the Aztec workings. The deposit is in decomposed trachyte in part stained and hardened by iron oxides and in part still light-colored and soft. On the hill above the mine there is a ledge of heavily pyritized trachyte.[4] The turquoise is found in seams filling pronounced joints and generally associated with limonite stains, and in balls or nuggets in leads through the trachyte or isolated. The nuggets are said to yield better turquoise than the veinlets. Streaks of gypsum occur in the trachyte near the turquoise leads. The turquoise from the Aztec claim is not of so good grade as that from the other claims. Much of it is rather soft and pale. Some of the turquoise with good color when fresh fades somewhat on exposure.

American Turquoise Company mine.—The American Turquoise Company mine is a little over 1 mile north of west of Turquoise Mountain and a few hundred yards west of the Cameo claim.[5] This mine was opened by a shaft 60 feet deep with a drift and raise to an open cut, and by another open cut about 150 yards to the north. The country rock is fine-grained light-gray to grayish-yellow stained altered trachyte. Specimens obtained from the dump contained inclusions of darker rock, also altered. These inclusions may be from the lower part of the trachyte sill where fragments of the underlying andesite were caught up. The workings are in a direction of N. 10° E., and evidently followed a pronounced vein, or set of veins, the dip of which is about vertical. The turquoise has been deposited in a fracture zone in veinlets and seams. It is said only pure turquoise was obtained from this deposit and that there was little material for cutting into matrix. The best turquoise has a good blue color and is quite hard.

M. M. Crocker claims.—The M. M. Crocker turquoise claims are the Azure No. 2 on the southwest end of Turquoise Mountain, and the Twilight, on a small knob one-half mile south of west of Turquoise Mountain. The work on the Azure No. 2 claim consists of a shaft 40 feet deep and an open cut at one place and an 8-foot pit a few hundred yards to the southwest. The 40-foot shaft was sunk in decomposed trachyte with andesite nearby on the east. A strong seam of turquoise running about N. 25° E. and vertical was encountered. In the pit several smaller seams of turquoise with about the same dip and strike were found in altered trachyte.

The Twilight claim was opened by Mr. Robinson for Doctor Crocker by two pits. The country rock is trachyte and contains a few small seams of turquoise. Much of the turquoise is greenish blue, and the seams are bordered with heavy stains or films of limonite.

R. S. Chamberlain mine.—The Calmea claim of R. S. Chamberlain is on the east side of the northeast end of Turquoise Mountain.[6] The deposit was marked by large Aztec workings, and has been tested by pits by several prospectors. A 40-foot shaft sunk by Mr. Chamberlain with a drift to the east is reported to have encountered ancient workings to that depth and so extensive as to make further mining difficult. The deposit appears to be along the contact of trachyte and monzonite or andesite. Little was seen of the formation or of the quality of the turquoise found.

Mary Posey Mining Company mine.—The mine of the Mary Posey Mining Company is about one-third of a mile north of Turquoise Mountain.[7] A shaft was sunk at this point for silver. Turquoise was reported as found in this shaft.

Another claim, called the Le Feve claim and owned by parties in Clifton, Ariz., has been opened across a draw a little over half a mile S. 20° W. of Turquoise Mountain. A little turquoise was found here in soft decomposed trachyte.

Essentially nothing has been done in the turquoise workings since Sterrett's visit, and his report is so detailed and so complete that little need be added to it beyond the explanatory footnotes given. The only place not mentioned by Sterrett where I found turquoise is in a shallow pit a few hundred feet south of the Copper King mine. Characteristically the turquoise is in veins or rock that contained considerable pyrite, the oxidation of which has produced much clay and jarosite in the rock, which is Sterrett's "decomposed trachyte." The decomposed host rock is commonly the sodic facies of the monzonite, but it includes also Hidalgo volcanics, sandstone, diorite, and monzonite porphyry. A thin section of one specimen discloses that the turquoise is veined and replaced by jarosite and by clay minerals. No sign of the apatite generally so abundant in the fresher rock could be seen. The origin of the turquoise perhaps is, as described by Sidney Paige [8] for the deposits of the Burro Mountains, that the phosphate of the turquoise was derived from the original apatite by sulfate solutions produced through oxidation of the pyrite.

PRACTICAL CONCLUSIONS

The appraisal of the mineral possibilities of the Little Hatchet Mountains is directly related to the conclusion that the Eureka and Sylvanite districts were once continuous but were torn apart and brought to their present positions by movement on the Copper Dick and related faults. Prior to that faulting the now separate Sylvanite and Old Hachita stocks constituted a continuous gently dipping mass, sheathed by a contact-metamorphic halo, that lay sill-like for a distance of 7 miles or more. The ore deposits appear to have been confined to the body of this stock and to the enclosing rock within a relatively short distance of the contact, and they gradually changed northward from the type characterizing the present Sylvanite district to that characterizing the present Eureka district. The final picture, then, from the standpoint of the miner, is of an ore zone of limited depth and width that is restricted, like a bedded deposit, to a particular position within the sedimentary formations, and in which the ores change along the length of the ore zone from those in which native gold, accompanied by small quantities of sulfides, is the principal mineral of value, to those characterized by base-metal minerals containing only a trace of gold but appreciable silver. To the extent that the distribution of the deposits as now exposed may be accepted as an index, the productive part of the ore zone would seem to lie within the invaded rocks, in an elliptical jacket that extends not

[3] On the National vein on the northwest slope of hill 5150. (S.G.L.)

[4] The Aztec workings are at the sandstone inlier cropping through the diorite sill in the specularite area of sec. 11. (See geologic map, pl. 1.) Sterrett's "decomposed trachyte" at this place is jarositized sandstone and diorite, which outwardly closely resemble the decomposed jarositized sodic facies of the monzonite, and the "pyritized trachyte" is pyritized sill rock. (See p. 78.) (S.G.L.)

[5] The mine of the American Turquoise Company and the Cameo workings evidently are the workings along the Stiles vein, where the clayified and jarositized volcanic breccia of the wall rock outwardly resemble the jarositized sodic facies of the monzonite. (S.G.L.)

[6] On the National fault. (S.G.L.)

[7] The workings immediately north of the houses at Old Hachita. (S.G.L.)

[8] Paige, Sidney, The origin of turquoise in the Burro Mountains, N. Mex.: Econ. Geology, vol. 7, pp. 382–392, 1912.

more than 1,000 feet both above the roof and below the floor of the stock and probably less than a mile from the sides.

The immediate practical conclusions to be derived from this are that the mineralized country of the Eureka district should pitch southwestward until cut off by the Miss Pickle fault, and that the Miss Pickle-Copper Dick fault block should contain a hidden mineralized zone whose existence appears to have been unsuspected. (See pl. 13.) More important to the miner, however, than the existence of new prospecting ground are the depth to the ore zone, the character and richness of the ore, and the probable size and structure of the ore bodies. The approximate depth to the ore zone at any place can be deduced from the subsurface limits of the stock as shown on plates 12 and 13 and from other known facts of structure. Thus the main part of the Eureka zone, which crops out on the under side of the stock, should meet the Miss Pickle fault at a depth of about 5,000 feet. In the Miss Pickle-Copper Dick fault block the depth to the ore zone is probably progressively greater from east to west, as the ore zone pitches westward with the formations, and progressively greater from the Miss Pickle fault toward the Copper Dick fault. The estimated depth in this block to the shallowest favorable prospecting horizon, which is assumed to extend not more than 1,000 feet above the roof of the monzonite, ranges from about 2,000 feet at the east edge of the monzonite to possibly more than 10,000 feet at the west edge. Some small showings of galena and pale sphalerite that crop out in the Hidalgo volcanics (?) between Howells Wells and the Copper Dick fault apparently represent the outcropping frayed edge of this pitching ore zone.

As discussed in the section on zoning, the deposits should be silver-bearing base-metal deposits containing also tellurides, native gold, and arsenopyrite in a gangue of carbonates, quartz, and, toward the Sylvanite end of the zone, silicates. Their tenor is impossible to predict.

The deposits are likely to be chiefly narrow veins like those of the present Eureka and Sylvanite districts. As the deposits may have been distributed through too great a volume of rock (see p. 80), the shoots may be comparable in size only to those thus far developed (see pp. 84-85), but there is always the chance, in view of the limestone replacement deposits of the Hornet area, that conditions at some place or other along the ore zone were right for the formation of replacement deposits of appreciably greater size.

Because of the shallow depths to which the deposits can be examined, nothing very conclusive can be inferred concerning future prospecting in the Eureka and Sylvanite districts themselves. On the basis of present knowledge, the outlook for prospecting in the Sylvanite district at much greater depths than thus far attained would not seem favorable. The native gold content may decline at a relatively shallow depth, and inasmuch as no commercial shoot of gold ore has yet been developed, deeper exploration should be undertaken only with full recognition of the uncertainty. Figure 16 shows the apparent size, shape, and grade of the gold-ore shoots at the Little Mildred (Green) mine, and that information may in some degree be applicable to the Sylvanite district as a whole. There may be a zone of copper-tourmaline deposits below the present surface similar to that in the Buckhorn mine, but that is highly speculative, and moreover copper-tourmaline deposits are commonly so low in grade that they must be relatively large to be commercially attractive.

For the Eureka district, present knowledge suggests that any new shoots found will probably be similar in size to the shoots mined at the King, American, and Hornet mines, that is, ranging from 10,000 to about 25,000 tons each with a maximum gross value per shoot of about $500,000. Specific comments concerning individual mines are given below, and if the suggested exploration should lead to the discovery of new ore, these figures can be modified accordingly.

Should the Eureka and Sylvanite districts represent separate centers of intrusion, the situation with respect to the Eureka district would be much brighter. Considered by themselves, the prospects around Old Hachita are promising, and it might reasonably be concluded that solutions still carrying such quantities of ore when they reached the Cretaceous beds would have deposited much greater quantities where they had crossed the underlying Pennsylvanian and Lower Paleozoic limestones. A feasible place to determine the depth to the Paleozoic formations by drilling would be at the east edge of the bedrock flat north of the Copper King mine. In the Sylvanite district the outlook would remain unchanged, because under any interpretation the depth to the Paleozoic formations near the stock must be several thousand feet.

A few practical comments can be made concerning some of the individual prospects. One of the best hints for future prospecting is given by the structural control of the King 400 ore shoot; it should be worth while to prospect further the intersection of the King vein and the bedding-plane fault in search of a continuation of the King 400 shoot or for other shoots. The intersection of the Howard vein with the two bedding-plane faults that cross it may be equally attractive. Two papers published several years ago discuss the general relations between faults and ore shoots in transverse fractures [9] and may be of some help to the miner in evaluating this suggestion.

As mentioned on pages 44-45, the two main spurs of the Old Hachita fault, as well as some links between them, are mineralized, and hence the main branch, which does not crop out, is probably also mineralized and might be worth investigating. At the American mine the ore shoot seems to follow the intersection of the vein fissure and a marble-limestone bed, and if this favorable bed is not cut out by a widening of the stock downward, that intersection might elsewhere yield similar shoots. Some critical information probably could be obtained if the mine were unwatered. Prospecting between the Ohio fault and the Hornet mine might lead to deposits similar to those at the Hornet.

[9] Burbank, W. S., Geology and ore deposits of the Bonanza mining district, Colo.: U. S. Geol. Survey Prof. Paper 169, pp. 95–97, 1932. Lasky, S. G., Transverse fractures as coordinate structures: Am. Jour. Sci., 5th ser., vol. 19, pp. 452–462, 1930.

In the Sylvanite district, the Santa Maria vein was difficult to follow because it is broken by spurs from the Copper Dick fault, and prospecting elsewhere near the Copper Dick fault will probably encounter similar difficulties. At the Gold Hill mine careful sampling of the workings would be required to show how much of the aplite is low-grade ore; the chances are very great that not all of it is. At the Buckhorn mine, both the high gold content of the leached ore and the high silver content of the mixed ore are probably due to supergene enrichment, and the fresh sulfide ore should be fully exposed and sampled before assuming that it is as rich.

HISTORY OF MINING AND PRODUCTION

The earliest metal-mining locations in the Little Hatchet Mountains, according to records of the County Recorder's office, were made on January 1, 1871. Stone implements found in old turquoise pits in the Eureka district indicate much earlier activity. One romantic account [10] states that the district was named "Eureka" by the early prospectors because of that discovery. The earliest claims located were named the Colorado and the Grant, but the descriptions given in the location notices are too vague to indicate their present identity. The three best known and most productive claims of the present day in the Eureka district—the King, American, and Hornet—were located between March 1877 and April 1878. Prospecting was carried on at the same time in what is now known as the Sylvanite district, and the Buckhorn mine was discovered early in 1880.

Earliest activity centered around the Hornet mine. Prospecting was hampered by hostile Indians, and when the district was visited late in 1878 by Lieutenant Birnie [11] in the course of his explorations for the Wheeler Survey, "the only residents were Mexicans —in all about 20 persons." The protection offered by Birnie's command seems to have brought back the prospectors, however, for shipments of ore from the American mine are recorded for 1881, the company having entered into a contract with the Santa Fe Railway Co. to carry a carload of ore daily to the smelter at Pueblo, Colo. Ore was shipped from the King mine as early as 1878 [12] and from the Hornet mine at least as early as 1882, as indicated by an old settlement sheet from the Pueblo smelter dated June 3, 1882, which was shown me by A. J. Fitch of Hachita. Some of the ore from the Hornet was shipped to the smelter at Chihuahua, Mexico. An adobe smelter was built on the south side of the draw south of the American mine sometime during the earliest years, and a 30-ton water-jacketed smelter, the stack of which still stands, was built at the Hornet mine in 1883, but neither smelter operated for long. It is said that the Hornet smelter froze when first blown in because of the high zinc content of the ore, and was never blown in again. Burchard [13] reported in 1883 that a smelter was erected by the New Mexico and Illinois Co., which had found "a good quality of iron ore" for use as flux; the iron ore presumably was in the specularite area about 1½ miles southwest.

Activities subsided about 1885, perhaps because of the drop in the price of silver, but were again stimulated in 1902 by the building of the railroad, which connected the district with the smelting towns of El Paso, Tex., and Douglas, Ariz. A branch line, since torn up, also was built from Hachita to connect with the Southern Pacific at Lordsburg. A number of claims were located in the Sylvanite part of the range during that period, some the very ones from which gold ore was mined later, but the gold was not recognized until 1908. Early in February of that year, Ed and C. F. (Doc) Clarke, brothers, found placer gold in one of the small gulches, and the discovery set off a minor boom. One early account is as follows:[14]

> Gold in small quantities was obtained from many of the gulches on the west side of the mountains, though most of the washing was confined to the region north of Cottonwood and west of Livermore Springs. Dry washers and a few rockers were used, as water was scarce, and it is said that from $3 to $15 a day was recovered by a few men. The total placer production to 1909 is variously estimated from $2,000 to $3,500. In the early part of March, 1908, placer work had largely been abandoned and prospecting for gold-bearing ledges began.

In October, 1908, native gold and tetradymite were discovered on the Wake-up-Charlie claim, which had been located by "Doc" Clarke, and the real Sylvanite boom started when the news leaked out. The discoverer was Sol Camp, a Cripple Creek miner, who claimed that the tetradymite was sylvanite, gold-silver telluride, with which he had become acquainted in the Cripple Creek district. This gave the name of Sylvanite to the district and heightened the excitement, though there were some who recognized that the mineral was tetradymite.[15] Within ten days after the news of Sol Camp's discovery leaked out, "nearly 1,000 people had reached the place," and before a month the town had a newspaper, the *Sylvanite Sun*. Water sold for $1 a gallon. Excitement was still running high late in the year, but when Hill [16] reached the district in June, 1909, "only 70 remained in the tent village, with possibly as many more at the various prospects in the mountains." During 1908, the year of Camp's discovery, 133 tons of gold ore averaging $27 a ton were shipped, but during the next 4 years only 336 tons were produced, including 165 tons of copper ore from the Copper Dick mine, which had been discovered many years before.

Both the Sylvanite and Eureka districts were idle from 1913 to 1915. In 1916, the Copper Dick mine was actively exploited because of the high wartime price of copper, and a period of activity began at the American mine in the Eureka district in 1919, when the property was acquired by Charles Fowles. A 100-ton selective flotation mill was completed at the

[10] Jones, F. A., The new camp of Sylvanite, N. Mex.: Min. Sci., vol. 58, pp. 489–490, 1908.

[11] Birnie, Roger, Jr., Notes on mining districts: In Wheeler, G. M., U. S. Geog. Surveys W. 100th Mer., Ann. Rept. 1879, pp. 183, 245–246, 251, 1879.

[12] Idem, p. 251.

[13] Burchard, H. C., Report of the Director of the Mint for 1883, p. 592, 1884.

[14] Hill, J. M., In Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., Ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 338–339, 1910.

[15] Martin, G. A., Sylvanite, N. Mex.: Eng. Min. Jour., vol. 86, pp. 962–963, 1908.

[16] Hill, J. M., In Lindgren, Waldemar, and others, op. cit. (U. S. Geol. Survey Prof. Paper 68), p. 338.

American mine in 1926 and was operated through 1928. Fowles' operations, both at the American mine and on the National group of claims, kept the Eureka district active until his death in 1931, but since then hardly more than assessment work has been done. Sylvanite, which had been idle since 1917, began to receive attention again in 1932, when two groups of Wyoming men became interested in the Little Mildred (Green), Creeper, and Buckhorn properties. Mining operations were started at the Buckhorn mine late in 1934 and lasted for a little over a year, during which time nearly 1,300 tons of ore were shipped. Active prospecting was carried on at the Little Mildred and Creeper prospects during parts of 1934 and 1935. Buildings were erected and mining equipment installed at the Gold Hill mine in 1934, and some mining was done. The latest production from the range to the time of writing (1937) was from the Gold Hill mine and from the Bader placers.

Of the twenty or more leading prospects and mines in the Little Hatchet Mountains only five have been operated as producing properties; ore shipments have been made from many others but largely incidental to prospecting. Complete and exact records of production are not obtainable, even for more recent years, primarily because some small shipments by Hachita operators from other districts of the Hachita area—Big Hatchet Mountains, Sierra Rica, and Apache Hills—cannot be segregated from those made from the Little Hatchet Mountains. Lindgren [17] estimated that the value of ore produced to 1906 did not exceed $500,000. My own estimate, based on Lindgren's figures, on statements appearing in the annual volumes of "Mineral Resources of the United States," on figures kindly furnished by C. W. Henderson of the United States Bureau of Mines, and on my judgment as to the size of stopes and grade of ore at the several mines, is that total production through 1936 lies between 55,000 and 65,000 tons having a gross value between $1,000,000 and $1,250,000. Of that total, 6,000 to 7,000 tons valued at about $200,000 were from the Sylvanite district, and the rest was from the Eureka district. Of the production from Sylvanite about 4,000 tons was mined as copper ore from the Copper Dick mine; the rest, except for 2 tons of sorted galena ore shipped from the Silver Trail tunnel in 1936, was gold ore, mainly from the Buckhorn and Gold Hill mines. Production from the Eureka district included 60 tons of arsenic ore shipped as such from the Miss Pickle tunnel.

Of the total production, about half in both tonnage and value was mined prior to Lindgren's visit, and, in general, production seems to have been rather evenly spread over the life of the district. The years of greatest production were 1906-07, when about 4,000 tons of ore were shipped from the Copper Dick, Hornet and King mines; 1916, when 2,059 tons were shipped from the Copper Dick mine; 1919, when about 1,000 tons were shipped from the American and King 400 mines; 1921, when about 2,200 tons were shipped from the American mine and several cars from the King 400 mine; 1926-27, when the American mill was actively operated and about 13,000 tons were mined in the Eureka district; and 1935, when a little over 800 tons were shipped from the Buckhorn mine.

[17] Lindgren, Waldemar, and others, op. cit. (U. S. Geol. Survey Prof. Paper 68), p. 335.

MINES AND PROSPECTS

EUREKA DISTRICT

AMERICAN MINE

The American mine, the nucleus of a group of 8 patented mining claims owned by Mrs. Maude J. Fowles of Hachita, lies half a mile southeast of Old Hachita, the main shaft being almost at the quarter corner common to secs. 1 and 36. The 8 claims include the Alaska, Oregon, Maine, Florida, American, Ohio, Texas, and Virginia. (See pl. 20.)

The American claim was originally located on April 10, 1878, by W. H. Crane and Rufus R. Bennett. The earliest shipments appear to have been made in 1881, when a contract was entered into with the Santa Fe Railway to ship a carload of ore daily to the smelter at Pueblo, Colo. One carload of this ore yielded $41.50 a ton in silver. In 1890 a Col. Fitzgerald shipped a little ore to the smelter at El Paso, Tex. He was succeeded in 1894 by his son, Geo. F. Fitzgerald, who sank the shaft now known as the Fitzgerald shaft and shipped some ore to El Paso before closing down in 1895. Additional shipments were made by the younger Fitzgerald in 1903 and 1904, and the mine was then idle until taken over in 1912 by Robert Anderson, who shipped 73 tons of ore. The mine is said to have been leased by various individuals at different times thereafter, but there is no further record of production until the mine was purchased in 1919 by Charles Fowles, who operated under the name of the Durango Mining, Milling & Exploration Co. In 1921 he and Royal R. Sheldon reorganized the property as the American Group of Mines Co., and in 1924 began building the present selective flotation mill, using steam power and equipping it with Marcy rod mills, Wilfley tables, K & K flotation cells, and Dorsey classifiers. Operation of the mill is said to have been satisfactory, recoveries running about 75 percent for silver, 95 percent for lead, and 60 percent for zinc, but considerable difficulty was encountered in operating the steam plant because of the hardness of the water. Mine water was used, containing over 2,300 parts per million of dissolved solids, chiefly calcium sulfate. (See p. 11.)

Fowles sold his interest to the company about 1926. Operations continued until 1930, when the mine was permitted to fill with water—it is reported that 125 to 150 gallons a minute were pumped from the 250-foot level—and nothing has been done since. Tax title to the property was acquired in 1932 by Mrs. Maude J. Fowles, the present (1937) owner and the widow of Charles Fowles.

The lower part of figure 13 shows the areas mined during the principal periods in the mine's history. Records of production are incomplete, but it is estimated that a total of about 25,000 tons of ore has been mined containing silver, lead, zinc, and traces of gold and copper, having a gross value of close to $500,000. The following table is a record of shipments since 1904.

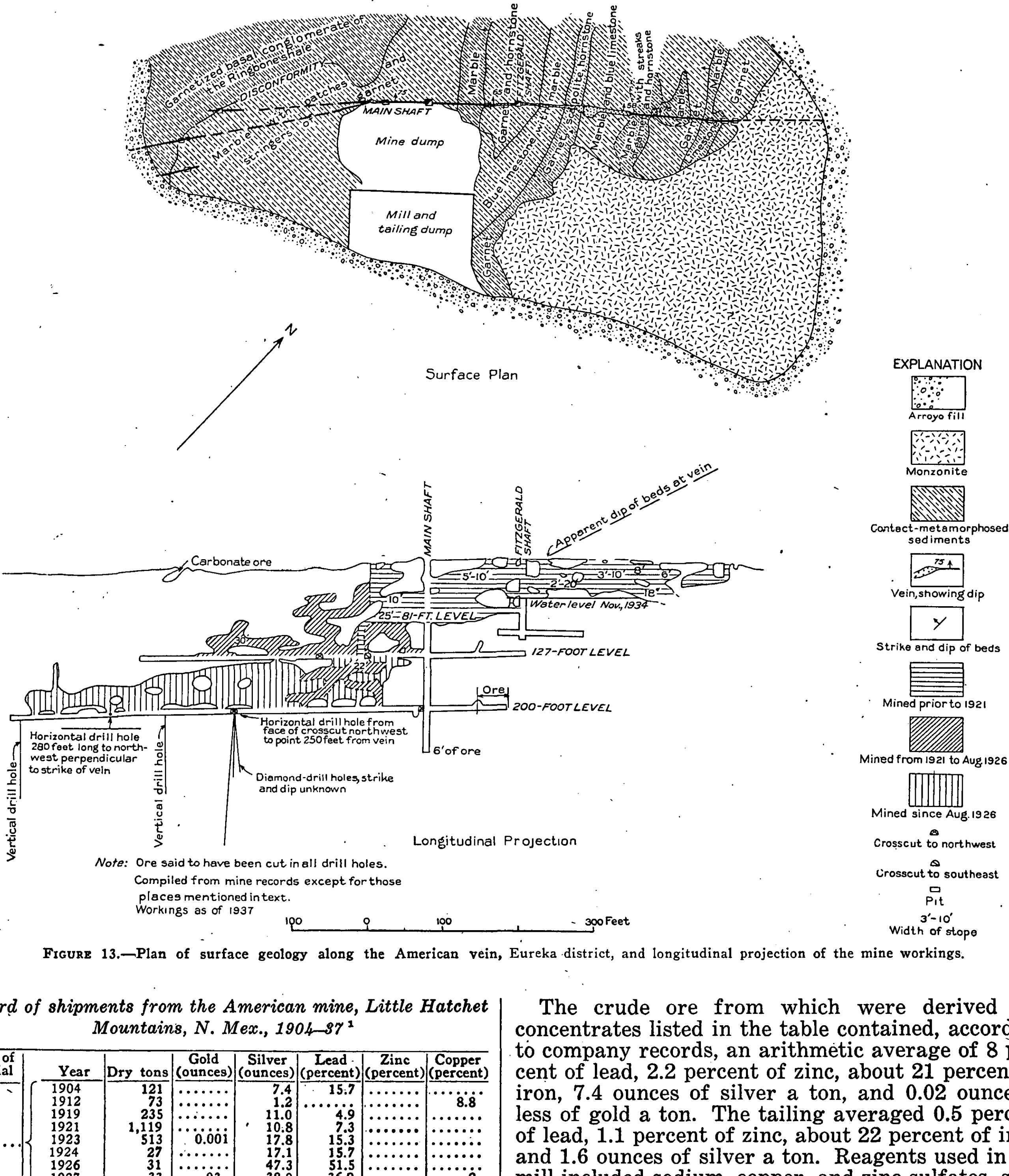


FIGURE 13.—Plan of surface geology along the American vein, Eureka district, and longitudinal projection of the mine workings.

Record of shipments from the American mine, Little Hatchet Mountains, N. Mex., 1904–37 [1]

Class of material	Year	Dry tons	Gold (ounces)	Silver (ounces)	Lead (percent)	Zinc (percent)	Copper (percent)
Crude ore	1904	121	....	7.4	15.7	....	....
	1912	73	....	1.2	....	....	8.8
	1919	235	....	11.0	4.9	....	....
	1921	1,119	....	10.8	7.3	....	....
	1923	513	0.001	17.8	15.3	....	....
	1924	27	....	17.1	15.7	....	....
	1926	31	....	47.3	51.5	....	....
	1927	33	.03	38.0	36.9	....	.2
	1928	38	.027	22.7	29.8	....	.25
	[2] 1929–37	....	....	....	....	....	....
Lead concentrates.	1926	271	.016	38.3	55.8	....	.1
	1927	921	.02	49.0	42.0	....	.2
	1928	67	.016	42.5	59.7	....	.4
	1929	122	.017	45.2	51.1	....	.3
	[2] 1930–37	....	....	....	....	....	....
Zinc concentrates.	1926	384	.017	26.0	6.2	42.3	.2
	1927	32	.009	30.1	6.6	41.5	.35
	[2] 1928–37	....	....	....	....	....	....

[1] Compiled from information furnished by C. W. Henderson of the U. S. Bureau of Mines, Denver, Colo.

[2] No shipments.

The crude ore from which were derived the concentrates listed in the table contained, according to company records, an arithmetic average of 8 percent of lead, 2.2 percent of zinc, about 21 percent of iron, 7.4 ounces of silver a ton, and 0.02 ounce or less of gold a ton. The tailing averaged 0.5 percent of lead, 1.1 percent of zinc, about 22 percent of iron, and 1.6 ounces of silver a ton. Reagents used in the mill included sodium, copper, and zinc sulfates, soda ash, cyanide, coal tar, and xanthate.

MINE WORKINGS

The longitudinal projection given in the lower part of figure 13 shows the extent of the mine workings as fully as could be ascertained. It was compiled, with the help of F. W. Snyder of the American mine, from sketches and other odds and ends of information found among the scanty mine records; the mine has never been surveyed, and at the time of my visits to the district the part below the 50-foot level was under water.

GEOLOGY AND ORE DEPOSITS

The ore deposits at the American mine lie along a vein that cuts metamorphosed Broken Jug limestone near the edge of the Old Hachita monzonite stock. (See fig. 13.) The vein strikes N. 50° E. and dips 58° to 75° NW. The outcrop is traceable for only about 1,000 feet, passing under the arroyo fill at each end, but shallow workings beyond the fill are on veins whose position and attitude would permit them to be continuations of the American vein. If so, the total outcrop length would be about 2,700 feet. The shallow workings to the northeast are 750 feet away at the outer edge of the metamorphic halo on the east side of the monzonite, and those to the southwest are about 400 feet away in the Hidalgo volcanics.

To judge from figure 13 and from a little additional information obtained from the few feet of underground workings open to observation, the ore lay within a shoot 50 to 100 feet broad and pitching 20° to the southwest, roughly parallel to the apparent dip of the sedimentary rocks. There is a strong suggestion that the ore shoot, as thus far developed, follows a marble-limestone layer in the metamorphosed sediments, the pillars, presumably barren, lying among the garnetite bands. The vein in the west end of the 200-foot level may lie in or near the monzonite, because the portion of the mine dump supposed to contain the waste from that part of the mine consists chiefly of the igneous rock, in part completely altered.

The stopes were partly accessible for about 100 feet east of the Fitzgerald shaft, and in that part of the mine the width of the stope, and apparently of the vein as well, ranges from 2 to 20 feet, the wide parts being at places where spur veins extend into the walls. Much cindery limonite is present along the walls and obscures the details of distribution of the various rocks. The limonite contains rounded vugs, tunnels, and galleries some of which extend into limestone wall rock beyond, and one gallery in the limestone is at least 15 feet long and as much as 2 feet wide. None of the cavities in the limestone are crusted with vein matter, nor is there any evidence that any vein matter has ever been there. Some of the gossan along the walls consists of garnet sand, probably in part due to supergene leaching of the calcite matrix of barren garnetite wall rock and in part to the leaching out of sulfides.

At the 50-foot level of the Fitzgerald shaft, the walls of the vein are marked by 2 to 24 inches of gouge and breccia. Black oxidized manganosiderite replaces the broken rock between the gouge slips, and stringers of ore penetrate the walls. A little fine-grained galena can be recognized in the stringers, and a 1-foot band of hard ore with streaks of galena lies along the footwall gouge at the back of the drift. As indicated by material in the ore bin and on the dump, the ore that was mined contained galena, sphalerite, pyrite, needles of arsenopyrite, and a trace of chalcopyrite in a gangue of fine-grained oxidized manganosiderite, calcite, and compact massive sericitic material. (See p. 72 and pl. 17, *C*, *E*, and *F*.) A few minute plates of barite were observed in some of the calcite. Some of the galena and pyrite evidently lay in pure bands 2 inches or more thick, and boulders of massive sulfides as much as a foot in diameter were seen in the bin. Zinc and lead carbonate ores are said to have been mined from the upper levels, and wire silver is said to be present in the vein at the bottom of the shaft. The earliest shipments contained silver chloride. The 73 tons shipped in 1912 was presumably chalocite ore.

The altered rock on the dump contains stringers of calcite and pyrite, and pyrite, calcite, and manganosiderite are distributed through the rock. The most thoroughly altered pieces seem to consist chiefly of the fine-grained sericitic material. The only quartz seen was in thin milky threads that cut the altered rocks. Drusy cavities in these rocks are lined with scalenohedrons of calcite (dog-tooth spar).

The grade of ore mined is suggested by the table of ore shipments given on a preceding page and by the explanatory statements thereto. The ore fed to the mill ranged from day to day as follows: Silver, 3.0 to 14.3 ounces a ton; lead, 2.0 to 16.7 percent; and zinc, 0.6 to 8.3 percent. The shipments of high-grade lead ore in 1926, 1927, and 1928 were of sorted galena ore, and most of the shipments in 1923 also were of sorted galena ore. Shipments totaling 566 tons made in 1921 and 1923 contained 10.2 ounces of silver a ton, 6.2 percent of lead, 8.2 percent of zinc, 4.2 percent of lime, 6.4 percent of sulfur, 17.7 percent of iron, 5.6 percent of manganese, and 22.9 percent of insoluble material.

NATIONAL GROUP OF CLAIMS

The National group includes 8 claims—the National, Last Chance, Copper King, Esmeralda, American Extension, Maine Extension, Silver King, and Silver Queen—in part purchased from previous owners in 1926 by Charles Fowles and in part located by him about that time. In 1937 they were owned by the Charles Fowles Estate. The group lies east and southeast of Old Hachita and in part is continuous to the east with the claims of the American Group. (See pl. 20.)

The principal workings of the National group are described below, though the information available is meager, because most of the workings are under water. Much of it, particularly data on the mine workings, is quoted from oral descriptions by F. W. Snyder, engineering advisor to the Fowles Estate.

SILVER KING MINE

LOCATION AND HISTORY

The Silver King mine lies half a mile due east of Old Hachita and an equal distance northeast of the American mine. It is the largest of the workings that prospect the National fault, which crosses the Silver King, Silver Queen, and Maine Extension claims of the National group.

According to the County Recorder's office, the Silver King claim was first located by James Hartzog and I. B. Stone on Sept. 20, 1902. It was one of the group purchased by Charles Fowles in 1926, and, with others of the group, was operated by him until his death in 1931. It has been idle since. A little ore has been mined and shipped from the Silver King, but detailed records of production are lacking.

MINE WORKINGS

The Silver King mine was under water to the 60-foot level at the time of my visits to the district in 1934 and 1935. The inclined shaft is said to extend along the vein to a depth of 217 feet. At the 65-foot level a drift follows the vein westward an unknown distance and eastward for about 200 feet, with a 100-foot crosscut to the north near the face of the east drift and with an air shaft to the surface 120 feet east of the main shaft. A second level at a depth of 200 feet includes a crosscut to the south for about 80 feet and a drift westward for an unknown distance.

GEOLOGY AND ORE DEPOSITS

Plate 21 shows the surface geology along the National fault zone where it crosses the National group of claims. There the fault brings the monzonite of the Old Hachita stock and its metamorphic halo against the unmetamorphosed equivalents of the same beds and against the diorite sills in them. The direction of displacement appears to have been parallel to the dip of the beds in that vicinity. (See p. 44.)

In general, the National vein dips steeply northward, but at the Silver King mine, between the surface and water level, the dip undulates between the vertical and 70° S. The best underground exposure is at the air shaft. Near the bottom of that shaft the north wall of the vein consists of diorite sill and the south wall of monzonite porphyry dike, and the vein contact between them is a tight gouge seam 2 to 3 inches thick with limonitic parts 10 inches or less thick. Limestone appears in both walls about 25 feet below the collar of the shaft, and the vein at once opens upward into several members, the main break being a broadly undulating surface whose troughs are as much as 15 feet across and 2 feet deep. A short stope extends east and west of the shaft at that level. At the surface the vein again is very tight.

No ore can be seen in place, and the only information as to its character and grade was obtained from the dump and from a few reported assays. The ore evidently consists of tetrahedrite, chalcopyrite, dark-brown to black sphalerite, fine- to medium-grained galena, and fine-grained pyrite in a gangue of manganosiderite, calcite, and a little quartz. The breccia pieces of rock cemented by this material seem generally silicified, and much of the rest of the dump material has a brown weathering stain derived from manganiferous carbonates distributed through it.

Samples of ore from different parts of the mine are said to have contained from a trace to 17.6 ounces of silver a ton, a trace to 0.08 ounces of gold a ton, 0.02 to 15.0 percent of lead, and a trace to 3.85 percent of copper. Zinc is not mentioned.

EIGHTH OF MARCH VEIN

The Eighth of March vein is a footwall spur of the National fault zone and dips from the vertical to 65° S. The principal workings lie on the Silver King and Silver Queen claims west of the Silver King mine. (See pl. 21.) All the shafts are isolated and contain only a small amount of subsidiary openings.

BONANZA SHAFT

The Bonanza shaft lies within the Silver King claim and is about 600 feet southwest of the Silver King shaft. It is 50 feet deep and at the bottom has an 80-foot drift to the west, an 80-foot crosscut to the south, and about 50 feet of irregular workings to the north. These workings were partly flooded at the time of my visit in December 1934. At 10 feet below the surface is the top of a stope extending east of the shaft for about 75 feet. The stope is 40 feet or less deep and has an average width of 5 feet, but the width of the vein is said to have averaged only a foot or less, the comparatively great width of the stope being due largely to sloughing of the heavy gouge and breccia walls and of the adjacent shattered rock.

As shown on plate 21, the shaft lies in metamorphosed sediments between outcroppings of monzonite, but the dump rock indicates that monzonite must have been cut in some of the workings at the bottom.

The ore, as represented by a pile on the dump, consisted of massive fine- to medium-grained galena, partly converted to anglesite and cerussite and said to contain as much as 80 ounces a ton in silver and an average of 0.05 ounce a ton in gold. Considerable early-generation pyrite is present. (Se p. 64.)

EIGHTH OF MARCH SHAFT

The Eighth of March shaft, also on the Silver King claim and 130 feet west of the Bonanza shaft, is 220 feet deep. Water stood at a depth of 60 feet in December 1934; it is said that the shaft at the time of sinking remained essentially dry to the 200-foot level, but was flooded by water later encountered in a drift to the north (?).

The dump rock at the Eighth of March shaft consists largely of monzonite cut by stringers of quartz, calcite, and granular pyrite like that on the Bonanza dump. A 7-foot vein is said to have been cut at the bottom of the workings, and the dump material reputedly from there shows galena, pyrite, chlorite, manganosiderite, calcite, and quartz veining and cementing sheared and brecciated rock.

SILVER QUEEN SHAFT

The Silver Queen shaft, 200 feet west of the Eighth of March, is 80 feet deep and has a 30-foot drift to the west at the bottom. The collar of the shaft is in garnetized sedimentary rock, but pyritized monzonite and monzonite porphyry dikes were cut underground. Some of the rock on the dump is stained brown from the weathering of manganiferous carbonates in it.

Assays of samples from along the vein are said to have shown a trace to 0.63 ounce of gold a ton, with an average of 0.02 ounce; 0.01 to 34 ounces of silver a ton; a trace to 25 percent of lead; and a trace to 0.4 percent of copper. Twenty-five tons of silver-lead ore shipped from the National group in 1929, believed to have been from the Silver Queen shaft, contained 0.012 ounce of gold a ton, 34.1 ounces of silver a ton, 25.1 percent of lead, and 0.1 percent of copper. In addition, 20 sacks of high-grade silver-copper ore, said to contain 840 ounces of silver a ton and 5.5 percent of copper, have been accumulated. The minerals recognizable in the sacked ore include prominent green and yellow horn silver, chalcocite, and malachite.

West of the Silver Queen shaft and across the draw, on the south slope of Turquoise Mountain, are other workings on the Eighth of March vein whose dumps contain specimens of specular hematite and barite.

COPPER KING MINE

The Copper King mine, supposed to be the original Jonsey claim, one of the earliest locations, is at the edge of the alluvium of Hachita Valley and on the road from Hachita to the American mine. (See pls. 12 and 20). It is half a mile southeast of the Silver King mine. The workings consist of a well-timbered shaft, said to be 100 feet deep but filled for a few feet at the bottom, an 85-foot crosscut to the north at a depth of 78 feet, an irregular open stope just east of the shaft and a second open stope about 150 feet east of that.

The shaft and stopes expose narrow oxidized stringers of chalcopyrite, pyrite, quartz, and calcite along a vein that follows the walls and central parts of a monzonite porphyry dike cutting limestone, limestone conglomerate, and red beds of the Broken Jug limestone. Scheelite was discovered on the dump in 1941. (See p. 67.) The stringers average 2 or 3 inches wide with a maximum of 18 inches. The strike of the vein averages S. 80° E., and the dip seems to range from 60° N. to 60° or 70° S. The shaft is vertical and leaves the dike and vein at a depth of 45 feet, vein and dike going out into the south wall. Both dike and vein become lost in the poorly exposed rocks of the pediment about 300 feet east of the shaft; west of the shaft the vein is traceable for about 650 feet and the dike a somewhat lesser distance.

Good assays in gold are said to have been obtained from the vein as now exposed, and about 100 tons of ore is said to have been shipped. Two shipments made by Tom Wright of Hachita, one of 20 tons in 1904, and one of 62 tons in 1919, may have come from this mine. The 82 tons yielded a total of 4 ounces of gold, 584 ounces of silver, 24,600 pounds of lead, and 7,650 pounds of copper.

KING VEIN

The King vein trends westward about a quarter of a mile north of the few abandoned houses that now constitute Old Hachita. The vein follows a set of monzonite porphyry dikes that cut the sedimentary rocks and their enclosed diorite sills, the dikes forming one or both of the vein walls over most of the exposure. (See pl. 22.) Dikes and vein appear to lie along the axis of a very shallow transverse syncline in the sedimentary rocks. One of the bedding-plane faults described in the pages on structure crosses the vein a little east of the King Gold shaft.

The King vein is really a zone of discontinuous or overlapping members. The principal workings, on the King 400 and King Gold claims, are on the most continuous of these members and mostly west of the bedding-plane fault zone; in fact, the King 400-King Gold ore shoot apparently rests upon this fault. The main workings and the geology of the deposits in them are described below; the other workings are very shallow and the vein as exposed in them is a narrow crushed zone, only 6 inches to a foot wide, which contains stringers of vein matter whose combined thickness does not exceed 4 inches or so.

KING 400 MINE

HISTORY AND PRODUCTION

The King claim, including the present King 400 claim and most of the King Gold claim, was located originally on March 19, 1877, by A. N. King and A. H. Butterfield and was one of the earliest locations in the Little Hatchet Mountains. A few tons of selected ore was shipped soon after the discovery, and in 1892 the western 400 feet of the claim was patented by the Owl Mining Co. under Mineral Entry No. 285 as the King 400 claim. (See No. 26, pl. 20.) In 1937 the owner of the King 400 claim was Albert J. Fitch of Hachita, who estimated that the total production from the mine, including the adjoining part of the King Gold mine (pl. 23), had a gross value of about $500,000, equivalent to a net value of $350,000. Fitch reports that he himself shipped 5,000 tons or so, which yielded a net smelter return of about $100,000. From Fitch's figures of production and grade, from some detailed records of shipments furnished by C. W. Henderson of the U. S. Bureau of Mines, and from the apparent size of the stopes, it is estimated that there has been mined a total of 10,000 to 15,000 tons of ore containing perhaps as much as 400 ounces of gold, 400,000 ounces of silver, 1,000,000 pounds of lead, and 1,200,000 pounds of copper, though the estimate of copper content may be very liberal. Latest work at the mine was in 1934, when 10 tons of ore was shipped and a little development work done.

MINE WORKINGS

The mine workings are shown in the upper part, projection, of plate 23. The mine has never been surveyed by transit and tape, and that part of the workings above water level as shown in plate 23 is from a Brunton-and-pacing survey made during my visit in 1935, the part below water level being sketched from an oral description by Mr. Fitch.

It is estimated that the level workings total about 800 feet. The stopes range in width from 1 foot, or just wide enough for a miner to pick out the vein matter, to a maximum of 9 feet; the average is about 3½ feet.

According to Fitch, only 10 to 20 gallons of water a minute had to be pumped from the mine at the 180-foot level.

GEOLOGY AND ORE DEPOSITS

The King 400 mine lies at a place where the vein crosses a 110-foot diorite sill in the Broken Jug limestone at the lower ammonite horizon. The hanging wall of the vein appears to have sagged down with respect to the footwall for about 7 feet along the underlying bedding-plane fault, and the ore shoot occupies the sag zone (pl. 23), lying without preference in limestone, diorite sill, and monzonite porphyry dike. Gouge and breccia are present along the sagged part, and the walls are slickensided, but at the western or upper limits of the sag zone the vein fades into tight stringers generally as little as a fraction of an inch in thickness. To judge from Fitch's description of conditions below water level, the bedding-plane fault zone is cut on the 180-foot level and in the shaft at a depth of about 240 feet, with the bottom of the shaft still in the fault zone; and the vein there feathers out into stringers none of which is more than 8 inches thick.

Two intermineralization faults cross the vein at right angles. They are postsulfide, for they offset the ore, but they themselves contain some pink, manganiferous scalenohedral calcite. One of them can be traced from the surface down past the 180-foot level.

All ore has been mined out from water level to the surface, and the only parts of the vein that can now be examined are at the backs and ends of some of the stopes. As seen there, the vein matter includes quartz, fine-grained and banded at the stringer walls, manganosiderite, calcite, chlorite, galena, sphalerite, small flecks and blebs of chalcopyrite, and crystals of pyrite. According to Fitch, tetrahedrite was common in the stopes below water level, and the silver of the ore is associated with it. Native silver is said to have been present in the vein just above water level. A little barite was noted on the dump.

KING GOLD CLAIM

The King Gold claim is now owned by Mrs. Maude J. Fowles of Hachita as one of a group of seven claims known as the Gold King group. (See pl. 20.) The workings include two shafts and some shallow openings and trenches. The deeper of the shafts is 195 feet east of the King 400 shaft; it was the main shaft of the original King claim and is reputed to be about 400 feet deep and to have 500 feet or so of lateral workings. Except for the open stope between the shaft and the King 400-King Gold end line (pl. 23), the workings are inaccessible, for the timbers are rotted away at the collar of the shaft and the connection with the King 400 on the 180-foot level is under water.

The collar of the King Gold main shaft is a few feet east of the lower contact of the King 400 diorite sill but within the monzonite porphyry dike. The top of the bedding-plane fault zone crosses the vein on the surface 90 feet or so east of the shaft and should be cut in the shaft at a depth of about 75 feet. (See pls. 22 and 23.) In this connection it is interesting that Burchard[18] reported that "for the first 60 or 70 feet [in the King shaft] the vein showed a width of from 1 to 3 feet of high-grade ore, returns from 40 tons of which gave 200 ounces in silver to the ton.

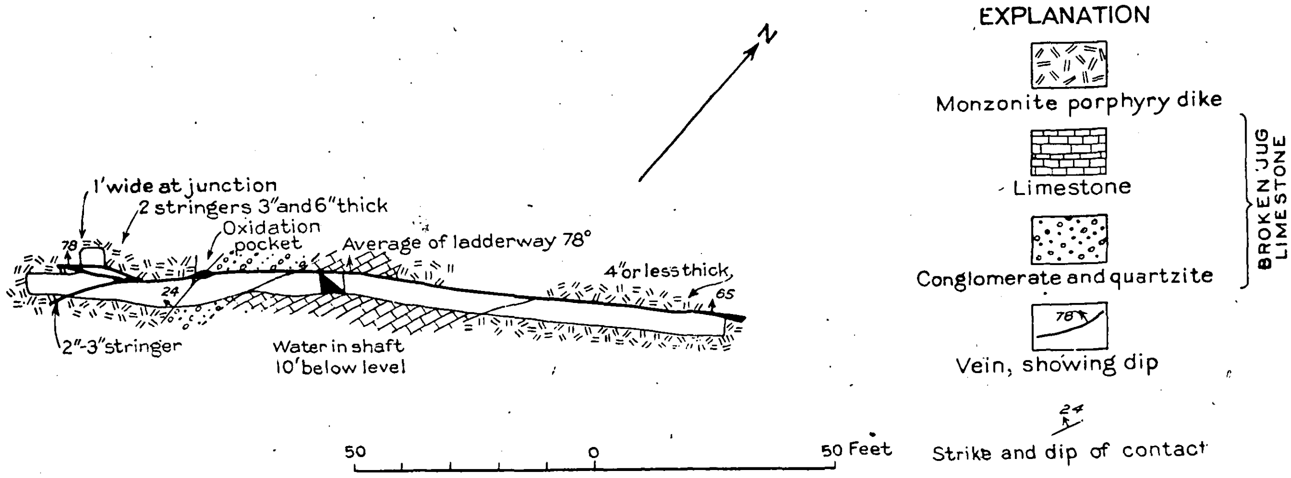


FIGURE 14.—Geologic map of the 60-foot level at the King Gold shaft No. 2, Eureka district.

The wall rocks are generally pyritized and cut by threads of pyrite, calcite, and quartz; and sericite, abundant manganosiderite, and calcite are distributed through the rock. So far as can be observed in the mine openings and from the dumps, there was only a trace of silicification. (See p. 77.)

Very little is known about the grade of ore mined from the King 400. According to Fitch, the ore from the east stope between the 180- and 220-foot levels contained an average of 45 ounces of silver a ton, 3 to 4 percent of lead, and 7 to 8 percent of copper. The 5,000 tons shipped by him is said to have averaged about 30 ounces of silver a ton, with copper and lead in proportion; a detailed record of shipments totaling 1,131 tons and made between 1919 and 1934 shows an average content of 0.027 ounce of gold a ton, 27.5 ounces of silver a ton, 3.3 percent of lead, and 0.8 percent of copper.

At the depth mentioned the vein pinched to a mere seam * * *." Fitch reports that a clay zone, such as that showing on the surface and such as he encountered in the King 400 workings, was cut in the King Gold shaft, but at what depth he does not recall.

The King Gold shaft No. 2 is 625 feet to the northeast at a point where the vein outcrop splits into two members. (See pl. 22.) On the 60-foot level the vein is tight and very narrow (fig. 14), but ore has been mined from an open stope starting 75 feet west of the shaft and having an inclined floor that meets the shaft about 30 feet above the 60-foot level. All other workings, if there are any, are under water. The vein on the level consists of oxidized, vuggy stringers of quartz, calcite, pyrite, and chalcopyrite, but the vein matter on the dump is like that at the King 400.

[18] Burchard, H. C., Report of the Director of the Mint for 1883, p. 591, 1884.

HOWARD VEIN

The Howard claim was located in 1879 and is one of the oldest in the district. At present the claim is known as the Gold Howard and is one of the King Gold group owned by Mrs. M. J. Fowles of Hachita.

The Howard vein passes through Old Hachita and is traceable eastward and westward to the wash for a total distance of about 2,500 feet. It strikes N. 60°-90° E. and roughly parallels the National and King veins, lying about midway between them. Its dip ranges from 73° NW. to 73° SE.

Like the King vein, the Howard vein follows a line of monzonite porphyry dikes cutting transversely through the sediments and diorite sils. (See pl. 5.) In structure and mineralogy the vein seems identical with the King vein. No tetrahedrite was observed, but a copper arsenate that suggests its presence was noted on the dump of the Howard shaft at the east edge of Old Hachita.

The principal workings are at the Howard shaft, which lies in the same position along the vein with respect to the bedding-plane fault zone as the King 400 shaft, though about twice as far from it. The collar of the shaft is at the disconformable contact between the basal conglomerate of the Ringbone shale and the massive beds at the top of the Broken Jug limestone. The upper diorite sill in the Broken Jug limestone crops out a few feet east of the shaft. The shaft is inaccessible but according to local reports is between 150 and 250 feet deep and includes among its lateral workings a long crosscut toward the King 400 mine. Rock of the *Exogyra* coquina beds that lie to the east makes up part of the dump, and presumably, therefore, the workings include a long eastward drift. Several cars of ore valued chiefly for the copper, silver, and minor gold content have been shipped, but no further information on production or grade of ore is available.

HORNET AND WASP MINES

The Old Hornet and Wasp mines, No. 3 on plate 12, are on the northwest side of an almost isolated limestone hill three-fourths of a mile southeast of the American mine. (See pls. 5 and 20.)

The patented Hornet claim was owned in 1937 by C. M. Abbott of Boston. It was one of the earliest locations in the Little Hatchet Mountains, and for a while was the seat of the greatest activity in the range. It was located on April 29, 1877, by J. Threllkell, J. S. Boon, and W. H. Case. Only meager details on production can be obtained, but according to local authority this may have totaled as much as 15,000 or 20,000 tons. The ore mined in the early days was shipped to the smelters at Chihuahua, Mexico and Pueblo, Colo., one settlement sheet from the Pueblo smelter dated June 2, 1882, showing a shipment of 5,675 pounds containing 27 percent of lead and 83 ounces of silver a ton. In 1883, 300 tons sent to the smelter are said to have averaged 140 ounces of silver a ton. A 30-ton water-jacketed smelter, the stack of which still stands, was built that year at the mine; it is reported that this smelter froze up on the first run and was never blown in again. According to incomplete records, production from 1905 to 1937 included about 3,500 tons of lead-silver and zinc-silver ores, all except a 32-ton shipment of high-grade zinc ore in 1916 apparently having been shipped primarily for the silver content. Latest production from the Hornet mine during this period was in 1927 when lessees shipped 44 tons of lead-silver ore to El Paso, Tex.

The country rock at the Hornet mine includes the main *Orbitolina*-bearing beds of the Broken Jug limestone, the overlying Hidalgo volcanics, and an irregular diorite sill that crosses the contact between them. (See pl. 5.) The limestone is in the same ledge of massive beds that forms part of the host rock at the American, Howard, and King 400 mines. Workings extend to a depth of at least 150 feet, according to an old map dated Feb. 1, 1883, but in 1935 the mine was under water to about the 75-foot level. Above that level the ore occupied irregular pockety bodies that honeycombed the limestone below the south end of the sill and below the basalt where the sill-limestone contact gives place to the basalt-limestone contact. The contact itself, at least between sill and limestone, is a fault, striking N. 50° E. and dipping 45°-60° NW., that forms the immediate hanging wall of the stopes at many places. Individual bodies of ore apparently were as much as 20 by 30 feet or more in cross section. A zone of mineralized stringers that may have constituted part of the feeding channels extends southeastward from the underside of the deposit.

The ore is said to have included three classes of material: (1) Lead carbonate ore, stained black by manganese oxides and averaging about 25 ounces of silver a ton; (2) galena ore, said to be still richer in silver; and (3) zinc carbonate ore, also rich in silver. The average metal content of the 3,500 tons of ore shipped between 1905 and 1927 was about 22 ounces of silver a ton, about 3.5 percent of zinc, less than 1 percent of lead, and about 0.05 percent of copper. The car of high-grade zinc ore shipped in 1916 contained 35.3 percent of zinc. A few other details of grade are given in the paragraph on production above. Well-developed crystals of pyrite accompanied the unoxidized material. The gangue consisted almost entirely of coarse-grained calcite, some of which may yet be seen along the walls of the workings as spheroidal masses as much as a foot in diameter. The walls of the stopes are meagerly silicified. The feeding fissures mentioned above contain limonite boxworks, a little malachite and azurite, barite, and calcite. All have narrow jasperoid walls.

The Old Wasp mine is a few hundred feet east of the Hornet workings and is entirely in the limestone. It includes several shafts on a short, nearly vertical fissure striking N. 55° E. The main ore body was a pipelike mass, 4 to 5 feet in diameter, 50 or 60 feet long, and raking 30° to the southwest. The ore was lead carbonate, said to have contained 30 percent of lead and 50 ounces of silver a ton. A little smithsonite, dry-bone ore, spots the stope walls, which here and there are stained with the dull-green lead-zinc-copper vanadate, mottramite.

MISS PICKLE TUNNEL

The Miss Pickle tunnel, No. 1 on plate 12, is a mile and a half southwest of Old Hachita and just at the east edge of sec. 3. The claim was located about 1924 by A. J. Fitch of Hachita, who in that year shipped a car of arsenic ore to the plant of the Chipman Chemical Co. near San Francisco. All told, shipments from the mine include 30 tons of lead-zinc ore and two lots of arsenic ore totaling about 60 tons. One lot of arsenic ore contained about 30 percent of arsenic, and the other contained about 15 percent of arsenic, 6.8 percent of lead, and 2.4 ounces of silver a ton; the lead-zinc ore contained 25 percent of lead and 5 ounces of silver a ton.

The mine is opened only by a 100-foot tunnel following a steep transverse vein fissure that appears to be within the zone of the Miss Pickle fault. The outcrop is so faint as to be practically unrecognizable except where exposed in an arroyo at the portal of the tunnel. The country rock consists of sandstone, limestone conglomerate, and red shale of the Howells Ridge formation. The ore forms small replacement pods along the vein and consists of fine-grained intergrowths of sphalerite, galena, and small needles of arsenopyrite (mispickel). Arsenopyrite also conspicuously impregnates the adjacent wall rocks, particularly a dark calcareous quartzitic sandstone that the miners call diorite. (See pl. 18, *A, B*.) Pyrite and chalcopyrite are rare. The oxidized material on the dump is deeply stained by brown scorodite. The gangue consists of the country rock and perhaps a little vein calcite.

SILVER BELL MINE

The Silver Bell mine is an old prospect 1½ miles south of the Hornet mine in the upper *Orbitolina*-bearing beds of the Broken Jug limestone and about 200 feet east of the contact with the Hidalgo volcanics. It is indicated as No. 4 on plate 12.

The workings include several irregular pockety pits in iron-stained limestone and one inaccessible untimbered shaft estimated to be 150 feet deep and having a dump whose size suggests several hundred feet of workings. The dumps show a little fine-grained specularite distributed in fresh limestone, a little pale-yellow pyrite, galena and its oxidation products, and coarse calcite like that at the Hornet mine. With the exception of the specularite, the deposit in general seems to have been like that at the Hornet.

SYLVANITE DISTRICT

COPPER DICK MINE

The Copper Dick mine is on the north slope of Hachita Peak and just south of the low pass followed by the road from Howells Wells to Sylvanite. It is 700 feet south of the Copper Dick fault. (See pl. 12.)

The Copper Dick mine was discovered by J. B. Tyler and located on April 17, 1890, and was patented by Tyler the following year. In 1935 it was owned by Tyler's heirs, with the active management in the hands of Dick Tyler, of Conneaut, Ohio. Production records for the Copper Dick mine are incomplete, but the total output must have been close to 4,000 tons of copper ore yielding net smelter returns estimated at $80,000 to $100,000. The period of greatest and most continuous activity was during the war years of 1916 and 1917, when the mine was leased by A. J. Fitch of Hachita, who shipped 2,596 tons of ore containing 3.6 percent of copper and 0.7 ounce of silver a ton. The net smelter return on this ore was $9.81 a ton.

The deposit was originally opened by an inclined shaft and by drifts that extended for 100 feet or so each side of the incline. The ore was stoped to the surface, but all surface openings are now dangerously caved and the workings are accessible only for a few feet; they are said to extend to a maximum depth of 80 feet.

The deposit lies in the metamorphosed Broken Jug limestone bordering the Sylvanite stock, whose nearest outcrop is 1,100 feet to the west. The general features of the setting of the deposit are somewhat as shown in figure 15, but the details are obscured by the dumps and caved workings. The deposit is

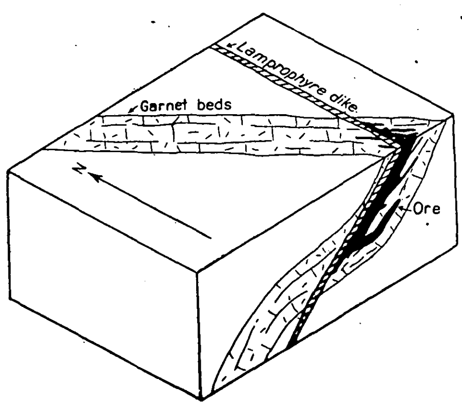


FIGURE 15.—Isometric sketch showing general geologic features at the Copper Dick deposit, Sylvanite district. Not drawn to scale.

blanketlike in form and lies within the garnet members of the metamorphic rocks at the intersection of a lamprophyre dike with a monoclinal warp in the beds, which strike N.35°–45°W. and dip 5°–50°SW. The dike strikes nearly due north and dips 40°W.; it can be traced south of the caved workings for 75 feet and north of them for 150 feet. A post-ore fault, striking N.70°W. and dipping 70°N., cuts the beds in the hanging wall of the dike but does not offset the dike appreciably.

It is said that there were two separate ore-bearing beds 30 to 40 feet apart. The main body was directly beneath the dike and is said to have been about 100 feet in diameter and 8 to 10 feet thick. A little ore lay along the bedding planes of the garnetite above the dike, and to judge from the size, shape, and distribution of the caved workings, good prongs of ore lay along the bedding planes below the ore body. One of these prongs was at least 100 feet long and about 2 feet thick. The ore in the main bed is reported to have contained 25 to 30 percent of copper, grading to about 10 percent at the edges; the lower layer contained 2 to 3 percent of copper. All ore carried silver and gold to the extent of 0.5 to 2 ounces of silver a ton and 0.02 ounce or less of gold a ton and consisted of massive chalcopyrite accompanied by a little pyrite. The associated gangue, in addition to the garnet of the host rock, included epidote, a hard slaty chlorite in large crystalline plates, actinolite, coarse-grained orthoclase, albite, calcite, and quartz. These and the ore minerals cut and replace the garnet rock, which also contains dissemniated chalcopyrite and pyrite. (See pl. 19, *C*.) Only the garnet beds appear to have been notably mineralized, and wherever ore has been found within the claim it lies within a garnet bed. The adjacent beds seem to contain only a little disseminated pyrite, and although the lamprophyre dike is epidotized and veined by stringers of ore and gangue, such stringers are rare.

Notable oxidation of the ore is said to have extended to a maximum depth of only about 10 feet.

A little ore has been mined also from some open cuts and from two 15-foot shafts on the first ridge to the east, just at or inside the end line of the claim and 400 feet south of the Copper Dick fault. The mineralized zone there can be traced nearly due west for 125 feet, but the most prominent individual break within it is a vertical fault at the eastern shaft, apparently post-ore, that strikes S.60°W. toward the main Copper Dick workings. A small pocket of ore was stoped from the south side of the fault near the surface, and an irregular pocket about 3 times as large and roughly 25 feet long, 10 feet high, and 4 feet wide, was stoped from the north side of it at the bottom of the shaft. The ore appears to have been similar to that at the main deposit but in addition contained coarse-grained magnetite. All told, shipments from these workings amounted to 48 tons containing 0.05 ounce of gold a ton, 1 ounce of silver a ton, and 7.3 percent of copper.

GOLD HILL (HARDSCRABBLE) MINE

GENERAL FEATURES

The Gold Hill mine (No. 6 on pl. 12) lies near the head of Stone Cabin Gulch a mile south of east from Sylvanite and half a mile southeast of the Green mine, but by road it can be reached from those places only through Hachita, which is 21 miles distant. (See p. 7.) The principal workings are at the bottom of Stone Cabin Gulch, 200 to 400 feet below the crest line of the adjacent ridges. In 1937 the property was owned by the Hidalgo Gold Mines, Inc., of Denver, Colo., and included the patented Silver Lake, Hardscrabble, Owl, Martin, and Norton claims, the Gold Acre group of 8 unpatented claims, and the Monrania and Ridgewood claims. (See p. 94, pl. 20.)

The original locations, the Martin and Norton claims, were made by J. E. Predmore on March 13, 1908. Under the name of the Gold Hill Mining & Milling Co., Predmore and Mike Wilcox shipped to the Copper Queen smelter at Douglas, Ariz., 880 pounds of sacked ore, said to have averaged 7 ounces of gold a ton, and about 100 tons of 1-ounce ore. In 1909 the mine was acquired by A. E. Carlton, of Cripple Creek, Colo., who did a little development work that year. The Hardscrabble Mining & Milling Co., which was formed the same year to take over the property, shipped some ore to the Copper Queen smelter in 1909 and 1910. One test lot of high-grade ore was shipped in 1911 and several tons in 1912. The Hidalgo Gold Mines, Inc., acquired the property in 1932; in 1934 they erected surface buildings and installed mining equipment and shipped two lots of ore totaling 41 tons. The mine was idle at the time of my visit in November 1934, but an additional 29 tons, sorted from the dump, was shipped in 1936. Total shipments from the mine through 1936 were close to 300 tons having an approximate gross metal content of 380 ounces of gold, 135 ounces of silver, and 3,800 pounds of copper.

GEOLOGY AND ORE DEPOSITS

The country rock of the Gold Hill area includes the metamorphosed sediments of the Howells Ridge formation, which there strike about due northwest and dip 35°–50°SW.; some monzonite dikes and sills, some of which are prongs from the Sylvanite stock; and a group of overlapping, steeply dipping aplite dikes. The several aplite dikes form a string that can be readily traced for some distance each way from the mine, the western end cutting well into the stock and the eastern end into the sediments beyond the metamorphic halo. (See pl. 1 and insert, pl. 24.)

The Gold Hill mine lies upon one of the aplite dikes, which are called syenite by the miners. (See pl. 24.) This dike is broken by a set of prominent longitudinal joints that dip from the vertical to 55° either side, and locally crossing these joints at approximately right angles to their strike are two other sets, not so well developed, that dip flatly against one another. The vein matter apparently is largely confined to places along the longitudinal joints—though a little lies in the cross joints, and stringers and patches have been noted in the country rock beyond the dike—and consists chiefly of quartz stringers with silicified rock between. Most of the stringers are generally only a fraction of an inch thick, but many reach a thickness of 6 inches and some locally as much as 2 feet. A trace of chlorite and streaks of muscovite are associated with the quartz. Pink to gray calcite is prominent at places, and a little pyrite and specular hematite and somewhat more abundant chalcopyrite, threads of which vein the calcite. (See pl. 19, *A*, *B*.) Traces of sphalerite and galena can be recognized in some polished hand specimens. Tetradymite and native gold are associated with the calcite and less commonly with the quartz. The gold is commonly visible to the unaided eye, though the largest particle seen was only about twice the size of a pinhead. Arsenopyrite lies along the joints at one place, and nearby a little white asbestos lies along one of the cross joints. Here and there the cracks of the shattered rocks, both in the aplite and the enclosing formations, contain bunches and stringers of black tourmaline. Stains of copper and bismuth carbonates are common. Carload lots of the ore shipped contained 0.65 to 2.60 ounces of gold a ton, 0.25 to 0.60 ounce of silver a ton, and an average of about 0.65 percent of copper.

A little ore, including most if not all of that shipped in 1934, has been mined from the two adits shown in plate 24, but most of the output, including most of the 100 tons or so shipped in the early days, came from open cuts on the west side of the gulch and about 75 feet above the adit level. There the aplite dike cuts a monzonite sill, presumably the same as that in the west adit. Some surface workings dot the east side of the draw near the tip of the tunnel dike and on the contacts of the next member of the aplite string. Tourmaline is common in all the surface workings.

Oxidation is meager and shallow.

RIDGEWOOD MINE

The Ridgewood workings are at the bottom of a draw about 750 feet due southeast of the Gold Hill mine. (See pl. 12.) The property includes two claims, the Ridgewood and Monrania, owned by the Gold Hill mine. Seven tons of ore, containing a total of 10.87 ounces of gold and 2 ounces of silver, was shipped from these workings in 1909.

The workings consist primarily of two tunnels that prospect a dark monzonite sill about 100 feet thick in the metamorphosed beds of the Howells Ridge formation. The sill is a pronged mass and apparently contains bedded slivers of hornfels. The main tunnel includes 200 feet of branching drifts and crosscuts. A quartz-limonite stringer is exposed in the back near the portal, and a typical stringery, branching quartz-calcite-tourmaline Sylvanite vein with albite borders is exposed for about 30 feet near the face. Other vein minerals include muscovite, scapolite, orthoclase, much chlorite, traces of pyrite and chalcopyrite, and native gold. The monzonite wall rock seems well pyritized. The vein strikes about due east and is steep.

Some open cuts and shallow shafts on the slope above the tunnel expose, for about 60 feet, a vein of similar mineralogy striking due east and dipping 70°N., which may be the same vein as that cut in the tunnel. The ore shipped in 1909 may have come from these workings.

The second tunnel is about 75 feet down the draw from the first and in the opposite bank. It is a looped opening 135 feet long in the sill near the top. A few feet of a tourmaline-albite vein is exposed at one place in the tunnel; a raise follows this vein to the surface, and a little stoping appears to have been done.

GREEN (LITTLE MILDRED) MINE

The Green (Little Mildred) gold mine, No. 8 on plate 12, is half a mile up the canyon west of Sylvanite. The claim was originally located during the boom days of Sylvanite, but it is said that the present vein was discovered in 1920 by Sam Morrow, who had relocated the claim as the Little Mildred. George Green, after whom the mine is now known, obtained the Little Mildred claim in 1923; in 1932 it was acquired, together with adjacent claims, by a group of Wyoming men organized for that purpose as the Sylvanite Gold Mining Co. The only ore shipped was a test lot of 101 tons in 1935 that contained a total of 45.09 ounces of gold, 45 ounces of silver, and 30 pounds of copper.

The mine, the workings of which are shown in plate 25 and figure 16, lies within a tongue of garnetized limestone and limestone conglomerate of the Howells Ridge formation between two of the main sill-like prongs of the Sylvanite stock. Narrow dikes and sills of the monzonite, as well as some lamprophyre dikes, are cut in the mine workings; a latite dike and aplite dikes like that at the Gold Hill mine are exposed in the lower tunnel and crop out on the surface. Most rocks appear well pyritized. The vein dips from the vertical to 60°SE. and has an average strike of N.78°E. It is traceable for 1,000 to 1,500 feet, the western end of the outcrop lying along the latite dike. As thus far exposed, the vein pinches and swells, erratically and rapidly, from a mere joint to a maximum width of 10 feet, the average being about 2 feet or less. A little gouge and breccia lie along the vein here and there, at least some of it being post-ore.

The vein material includes almost a complete sequence of the Sylvanite minerals. The wall rocks for as much as 2 feet or so bordering the vein fissure are altered to a white and pinkish fine-grained albitite, and within these walls, cutting and replacing the rock, are stringers of fine-grained tourmaline, locally very prominent. Veins of coarse-grained white quartz a foot or less thick cut the albite-tourmaline rock, and associated with the quartz are small pockets of actinolite and chlorite. Calcite is present locally. The most prominent metallic mineral is tetradymite, with which is associated native gold and hessite; the other metallic minerals include small amounts of pyrite and chalcopyrite and traces of sphalerite, galena, and, at one place, arsenopyrite. The hessite is so thoroughly masked by the tetradymite as to be recognizable only under the microscope (pl. 15, *F*), but the gold is readily visible in grains as much as 1/16 inch in diameter and as threads cutting the quartz. The ratio of silver to gold in a list of 68 assays is 1½ or 2 to 1, the hessite accounting for the comparatively high silver content; the ratio was 1 to 1 in the 101 tons of ore shipped. Gold assays range from a trace to a maximum of 5.40 ounces a ton over vein widths ranging from two inches (corresponding assay, 5.40 ounces a ton) to 5 feet (corresponding assay, 0.04 ounce a ton). Silver assays in the same group of samples range from a trace to 2 ounces a ton.

Development has advanced hardly enough to permit generalizations concerning distribution and average grade of the ore shoots, but the available assays indicate a distribution and grade somewhat as shown in figure 16.

CREEPER TUNNELS

The Creeper tunnels, on the Bonner No. 3 (Creeper) claim of the Sylvanite Gold Mining Co., are on the west bank of Sylvanite arroyo a quarter of a mile above Sylvanite camp. (See No. 9 on pl. 12 and No. 45 on pl. 20.) The early history of the property is unknown; it was worked recently by George Green of the Green mine and was taken over by the Sylvanite Gold Mining Co. in 1934. To 1937, no ore had been shipped.

The mine workings are shown in plate 26. They consist primarily of two tunnels, 235 and 165 feet long, which prospect three neighboring veins at and near the edge of a small mass of Howells Ridge garnetite and hornstone in the Sylvanite stock. A lamprophyre dike lies along one of the veins just east of the portal of the lower (eastern) tunnel, and others crop out nearby. The veins are much like that at the Green mine, though containing different proportions of ore minerals. White albitized walls and tourmaline are characteristic. Other gangue minerals are coarse-grained white quartz, a little calcite, and associated small pockets and needles of dark green actinolite. By far the most abundant ore mineral is arsenopyrite, which tends to form isolated pods and kidneys that replace the albite-tourmaline rock. (See pl. 17, *D*.) The discovery shaft and the shaft workings at the portal of the upper tunnel are on two such pods, which appear to have been as much as 40 or 50 feet in diameter and 9 feet or more thick. The only other sulfides are pyrite, which in part is disseminated in the wall rocks, a little chalcopyrite, and secondary chalcocite. Tetradymite is rare, at least in those parts of the vein thus far explored; no gold has been observed, but assays prove its presence in small amounts. A brown and a subordinately green scorodite are prominent in the very shallow oxidation zone.

Post-ore faulting of the veins seems common, but the effect is insignificant.

HANDCAR VEIN

The Handcar vein, so-called, is a string of tight overlapping and linked members that strike N.40°–70°E. and dip 60°–80°SE. The string is traceable for nearly half a mile across a high ridge a mile due north of Sylvanite, from which the workings can be reached only by trail. The country rock is the quartz monzonite facies of the Sylvanite stock.

The Handcar workings were some of the best known in the boom days of the district, but very

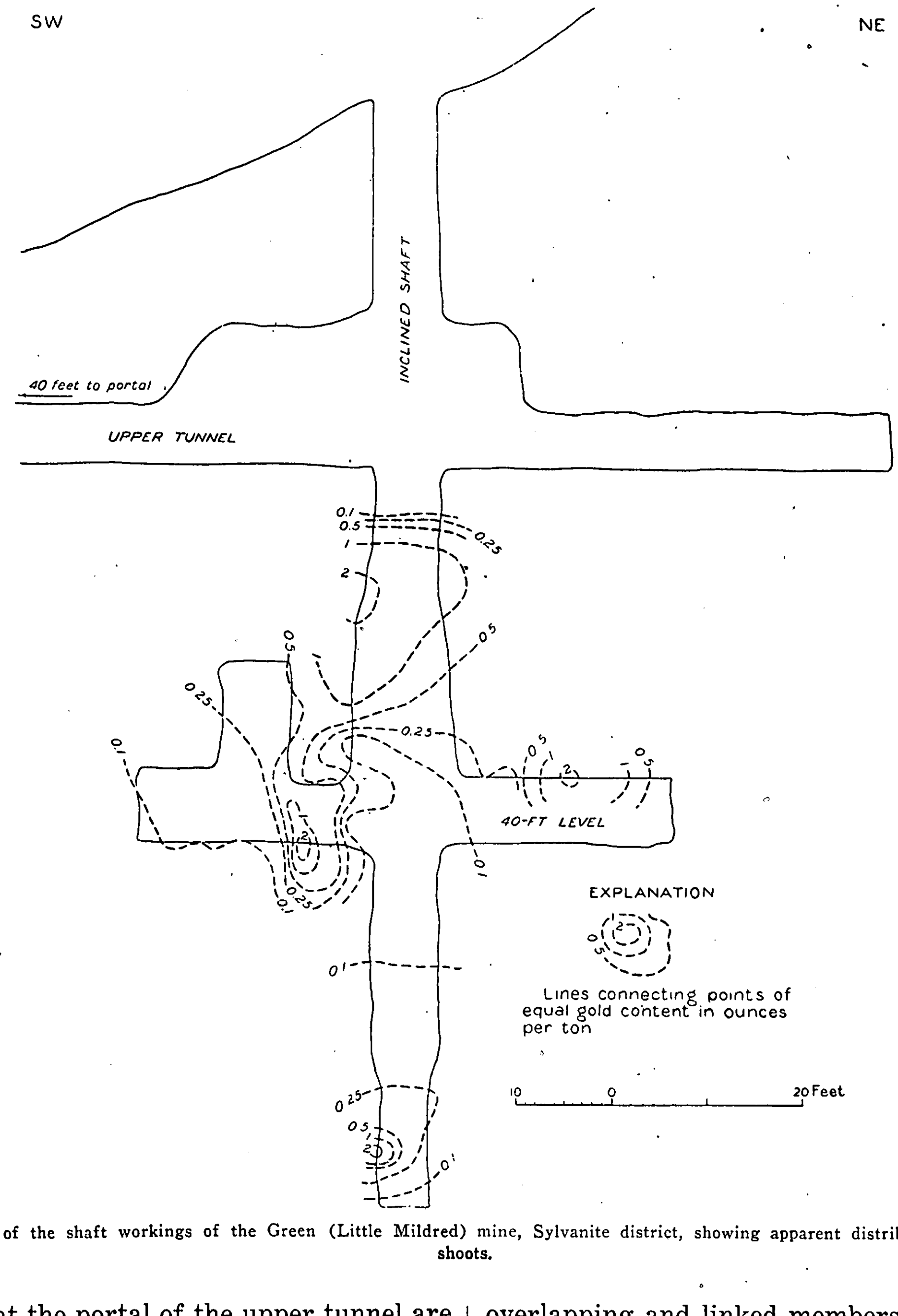


FIGURE 16.—Projection of the shaft workings of the Green (Little Mildred) mine, Sylvanite district, showing apparent distribution and grade of the ore shoots.

little, if anything, has been added to them since then. Most of the prospecting was in a 230-foot tunnel (fig. 17) near the south end of the vein outcrop. Three veins were cut in the tunnel workings. That at the portal is a narrow tourmaline vein having the characteristic albite border and containing oxidized pockets that indicate the original presence of a little sulfide. The two other veins range in thickness from tight stringers to a maximum of about 1½ feet and are quartz-pyrite veins containing a little chalcopyrite. Samples from the vein at the face are said to have run as high as 0.8 ounce of gold a ton and 0.5 percent copper. A trace of magnetite was found in one of the tight footwall spurs of the central vein.

About 400 feet toward the crest of the ridge is a large open cut on a 4-foot oxidized vein that may be an outcropping of the one at the tunnel face. The strike is N.55°E. and the dip 68°SE. The vein contains tourmaline, quartz, pyrite, and limonite, and has the characteristic albite border. It cannot be traced to the southwest beyond the dump, but it can be followed northwestward over the ridge and down the gully on the other side with the aid of some shallow cuts. Here and there the vein lies along a lamprophyre dike. Scattered workings still farther northeast on the same general trend mark the continuation of the vein zone.

About 500 feet north of this vein, beyond the ridge, a 20-foot tunnel with an 8-foot winze at the face prospects a parallel vein that lies along the contact between quartz monzonite and a small inclusion of metamorphosed sediments. Farther up the hill is an old 20-foot shaft on a third vein parallel to the others in strike but having a nearly vertical dip.

Ore from some of the surface workings is said to have contained tetradymite and free gold and to have yielded high assays, but there is no record of ore shipments.

BUCKHORN MINE

The Buckhorn mine, variously known also as the Wood, Barney, or Russell mine, is high up on the west slope of Hachita Peak at an altitude of 5,950 feet. It is readily reached by a 1½-mile branch road that leaves the Sylvanite road a little south of Livermore Spring, and altogether is 15 miles from the shipping point at Hachita.

The claim was originally located as the "Buck Horn Mine" on May 14, 1880, by John Doyle and M. J. Hinton. It was relocated at frequent intervals thereafter and early in 1934 was leased under option to a group of Wyoming men headed by George Blood, who excavated essentially all the stoped ground shown in figure 18. The owners at that time were J. G. Russell and M. T. Anderson of Hachita.

About all that is known of the early output of the mine is that 2,200 pounds of high-grade gold ore valued at $129 a ton was produced prior to 1909, and that in 1911 Harry Wood shipped 20 tons containing 9 ounces of gold, 8 ounces of silver, and 230 pounds of copper. George Blood began to ship ore in August of 1934 and by late August of 1935 had shipped a total of 1,258 tons containing 0.55 ounce of gold and 0.73 ounce of silver a ton and 0.3 percent of copper. The ore averaged 16 percent of iron, and 60 or 65 percent of silica. The net smelter returns averaged $12 a ton. The highest assays on carload lots were 1.69 ounces of gold a ton, 1.3 ounces of silver a ton, and 3.25 percent of copper; the lowest were 0.19 ounce of gold a ton, 0.4 ounce of silver a ton, and no copper. Two classes of ore were shipped: (1) Thoroughly leached and oxidized ore requiring as much as 25 cubic feet to a ton and containing 0.57 ounce of gold and 0.68 ounce of silver a ton and 0.07 percent of copper; and (2) mixed oxidized and sulfide ore containing 0.43 ounce of gold and 1.0 ounce of silver a ton and 1.6 percent of copper.

The mine workings lie within the metamorphosed Broken Jug limestone about 500 feet north of the Sylvanite stock and at the extreme west end of the vein outcrop, which has a general trend of S.70°E. and a dip of 70°–90°NE. (See pls. 1 and 12.) From there the outcrop extends through the saddle of the ridge, 115 feet above the tunnel level, down

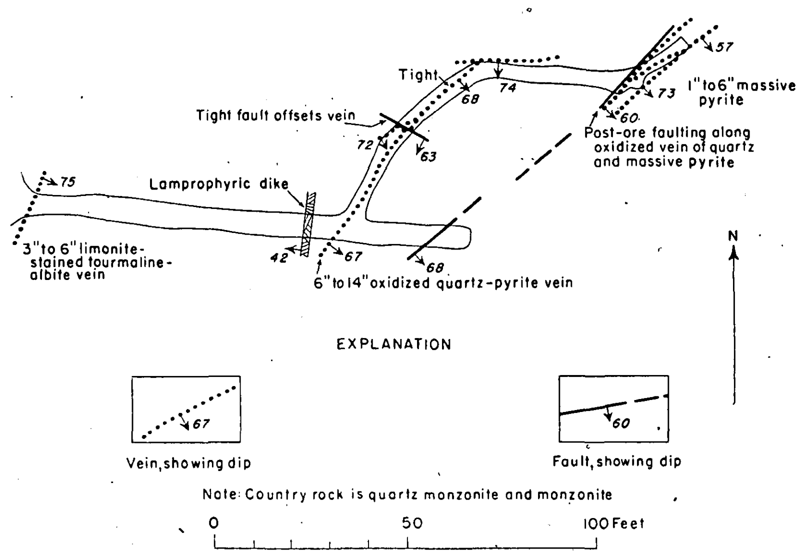


FIGURE 17.—Geologic sketch map of the Handcar tunnel, Sylvanite district.

the other side, and into the monzonite, lying along the north wall of a sheared lamprophyre dike for essentially the entire distance. It is traceable for 1,500 feet or more.

Within the tunnel the vein lies directly against the lamprophyre dike, which is sheared to a schistose rock for 3 feet or so from the vein wall. (See fig. 18.) The hanging wall there consists chiefly of the garnetized beds of the metamorphosed sediments. A dike or sill of monzonite crops out about 40 feet in the hanging wall, cutting over to the vein at the portal of the tunnel, and monzonite forms the width of the vein in the workings ranges from 1 to 15 feet or more, the average being 4 or 5 feet. The stopes are as much as 9 feet wide with an average of 5 or 6 feet.

The vein filling seems identical with that of the other gold veins of the Sylvanite district except that pyrite and chalcopyrite are much more abundant in the Buckhorn vein as thus far explored. The outcrop is marked by white quartz and contains a little tourmaline here and there. Within the quartz are small pockets of chlorite and muscovite. The dump matter at the several shallow workings along the

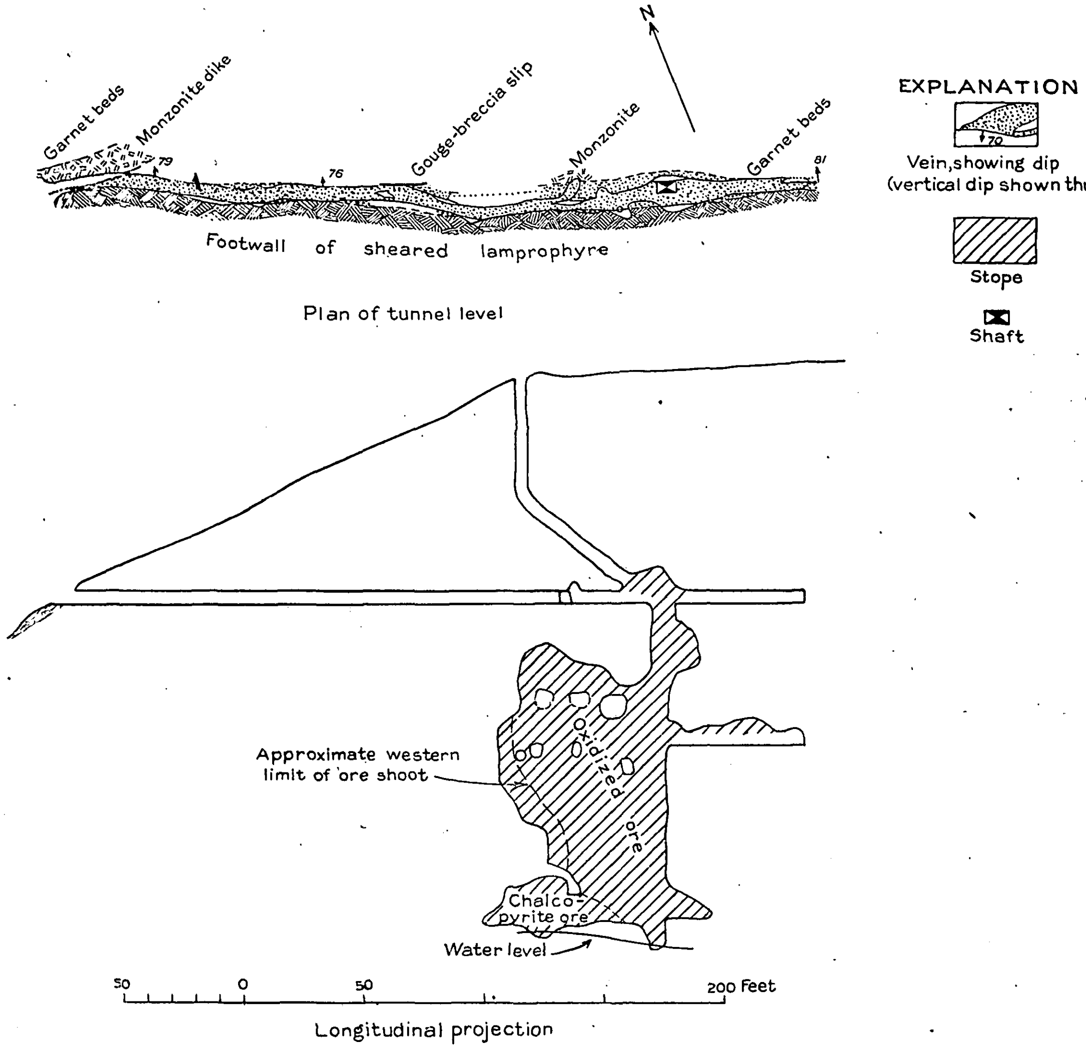


FIGURE 18.—Plan and projection of the Buckhorn mine, Sylvanite district. Workings as of August 13, 1935.

immediate hanging wall in a short crosscut near the shaft. Below the tunnel level, wall rock is exposed only in the east end of the bottom workings, where the footwall is the lamprophyre dike stained and decomposed by the oxidation of a great deal of disseminated pyrite. Elsewhere the walls of the workings consist of streaks of gouge and breccia or of slabs of quartz spotted in places with pyrite or their limonite casts. Similar slabs or ribs of quartz 2½ feet or more thick lie within the heart of the vein with ore on one or both sides. The outcrop contains chalcopyrite, pyrite, and jarosite. On the tunnel level at the Buckhorn mine the vein matter includes white quartz and considerable massive earthy and cellular limonite spotted with jarosite. At the edges of the stope below, the vein is filled with cavernous brittle, cindery limonite containing large streaks of wad and with open spaces as much as 1½ by 3 feet in size. Quartz, coarse-grained calcite, and pyrite, massive and disseminated, are exposed in the workings east of the shaft below the tunnel level, though leaching and oxidation in that part are still intense. Chalcopyrite and pyrite only slightly altered are abundant in the west end of the bottom workings, the 140-foot level (fig. 18), where they form chalcopyrite-rich slabs as much as a foot thick in massive quartz. A few flakes of tetradymite were seen in some of the material from that part of the mine, and a few spots of earthy bismuth carbonate were seen at the outcrop; the smelter returns for the shipments of mixed oxidized and sulfide ores show the presence of 0.01 to 0.11 percent of bismuth. The smelter returns show also 0.1 to 0.5 percent of zinc, present in both the oxidized and mixed ores, implying the presence of a little sphalerite, and the assayer reports arsenic, suggesting the presence of arsenopyrite as in other veins of the district. In places the vein matter includes soft, decomposed rock or streaks of gouge and breccia, which in part seem to be pre-ore.

Water level lies at the bottom of the mine, 225 feet below the surface.

WAKE-UP-CHARLIE MINE

The Wake-Up-Charlie mine (No. 10 on pl. 12), the workings of which were inaccessible at the time of my visits to the area, has been inactive since the boom days of the Sylvanite district, and this description is included here chiefly because the discovery of native gold and tetradymite there in October 1908 set off the Sylvanite gold rush. The claim was located on Feb. 24, 1908, by C. F. ("Doc") Clarke. Four carloads of ore averaging $40 a ton are said to have been shipped before news of the discovery leaked out, though no official record of those shipments can be found.

The mine lies within the Sylvanite stock on the low ridge between the forks of the Sylvanite arroyo half a mile above Sylvanite camp and just south of a very prominent postvein latite dike—called "trachyte" locally and the "later latite dike" of this report. About 100 feet from the dike is an open cut on an oxidized vein that strikes N.85°E. along the north wall of a lamprophyre dike. The vein is clearly traceable for only a few feet. Farther south, 120 to 150 feet, are two partly caved shafts 125 feet apart on a steep vein striking N.75°E. This vein can be traced for 50 feet beyond the eastern of the two shafts but not past the western one, where the vein seems to be only 1½ feet wide. A 2-foot lamprophyre dike parallels the vein 20 feet to the south, and the dump at the western shaft contains some of that rock. The western shaft is estimated to be about 60 feet deep and the eastern one about 100 feet deep. Twenty feet in the hanging wall of the eastern shaft is a 10-foot pit connected to the shaft by a short crosscut at the bottom.

South of the eastern shaft about 50 feet is an open cut on a third vein that strikes N.60°E. and dips 70°SE. The cut is 50 feet long and seems to be the caved portal of a tunnel.

The filling of these three veins, as indicated by the little that can be seen in place and by the material on the dumps, is like that of the other veins of the Sylvanite district. They are essentially albite-tourmaline-quartz veins with calcite and actinolite and containing a little pyrite, chalcopyrite, tetradymite, and native gold.

CLEMMIE MINE

The Clemmie mine (No. 13 on pl. 12) is of particular interest because it is so different in some respects from the other deposits of the district. It is a small prospect on the east side of the range 150 feet or so below the crest. It may be reached by trail from the Gold Hill mine a mile to the northwest and may be approached by car to within a quarter of a mile over an extremely vague and difficult road branching from the Alamo Hueco-Hachita highway at Eightmile wells.

The mine is near the edge of a band of metamorphosed beds in the Howells Ridge formation. A 60-foot tunnel, with a 25-foot drift to the southwest about midway in, roughly parallels the bedding of a quartzitic member in these beds. The quartzite is mostly fine- to medium-grained but contains coarser layers in part of which the marmorized cement has been replaced by pyrrhotite, so that the rock now consists of quartz grains in a pyrrhotite matrix. (See pl. 17, *A*.) A little chalcopyrite is intergrown with the pyrrhotite. The chalcopyrite is highly subordinate in the specimens I collected, but it is said that the pyrrhotite-bearing rock as a whole contains as much as 6 percent of copper. In addition, the quartzite is cut by numerous quartz stringers, ranging in thickness from the merest thread to an uncommon maximum of about 2 inches, that are similar to the gold-quartz veins of the district; they contain pockets and flakes of chlorite, scattered pyrite, a little chalcopyrite, microscopic hexagonal crystals of pyrrhotite, shreds of tetradymite, and native gold. (See pl. 17, *B*.) The 25-foot drift begins on one of these stringers but leaves it to follow a group of tight and rusty joint planes said to be gold bearing.

A 15-foot crosscut tunnel prospects the quartzite on the south bank of the draw opposite the main tunnel. Neither vein nor replacement ore were observed there, but the walls are crusted with a heavy efflorescence of iron sulfate. Shallow adits, pits, and trenches prospect the quartzite and adjacent hornstones up and over the ridge to the northwest along showings similar to that in the main tunnels, some of the ore matter at those places lying along the bedding planes of the rock.

It is said that 1,800 pounds of ore containing gold at the rate of 2 ounces a ton was shipped from the surface cuts by W. T. Holcomb and J. H. Slaughter shortly after they located the claim on April 21, 1908. In 1936 the claim was held by Mike Wilcox of Hachita.

PEARL (MONTE CRISTO) MINE

The Pearl or Monte Cristo mine (No. 14 on pl. 12) is one of the prospects upon which a little work was done about the time of my visits. It is in the first arroyo east of Stone Cabin Gulch and a little over three-fourths of a mile south of the Gold Hill mine. It can be reached readily by a road branching from the Gold Hill road 1½ miles beyond the Corbett Ranch and heading up the bed of the arroyo.

The property is said to have been located in March, 1908. Eight tons of ore containing 42.16 ounces of gold and 27 ounces of silver was shipped in 1909 by the Monte Cristo Mining Co. of Uvalde, Tex.

The workings are in the Howells Ridge formation beyond the main part of the metamorphic zone, though some beds are faintly marmorized and silicated. On the east side of the arroyo an adit 60 feet deep follows a steeply dipping quartz stringer that strikes N.85°W. through blue and brown limestone. The stringer is mostly less than an inch thick, and near and at the face of the tunnel the vein consists only of 10 inches of crushed and iron-stained rock. Halfway up the slope another tunnel, 90 feet deep and in green and brown limy shale and dirty limestone, follows a quartz stringer that is 3 inches wide at the portal but tightens to a mere joint at the face. The vein is trenched for 100 feet from just above the portal of this tunnel nearly to the top of the ridge, but it cannot be traced farther. The trench reaches a depth of 10 feet or more, and the high-grade ore that was shipped came from there, but it is reported that the vein is almost barren at the bottom of the trench. Hill[10] reported that the Pearl vein is as much as 8 feet in width, and the wide part presumably was the portion mined out at the open cut.

On the east side of the ridge is a third tunnel 80 feet deep and having a 10-foot winze at a depth of 20 feet and a second 10-foot winze at 60 feet. The vein at that tunnel is a partly oxidized quartz-calcite stringer that strikes N.85°W. through black shale. It is 8 inches or less wide as now exposed, but the excavated portion is said to have been as much as 18 inches wide. The vein matter is in part drusy and contains fragments and slivers of the wall rock; "beautiful specimens of free gold" are said to have been found in it. A thin sill of monzonite 2 to 10 feet thick crops out on the slope above the tunnel.

The stringers prospected by the different workings cannot be traced into one another and may or may not be parts of the same vein.

JOWELL VEIN

The Jowell vein was one of the best known in the boom days at Sylvanite, but nothing seems to have been done on it since. It is close to the center of sec. 29, three-fourths of a mile northwest of Cottonwood Spring and a fourth of a mile south of the Copper Dick fault. (See pl. 12.) The Sylvanite road passes within a few hundred feet of some of the workings.

The country rock along the Jowell vein consists of monzonite and metamorphosed beds of the Howells Ridge formation. The vein is traceable not more than 1,000 feet but may be somewhat longer, for a gravel-filled draw follows the line of the vein to the southwest. A shaft at the southwest tip of the present exposure shows that the vein has a dip there at the collar of 80° SE. and a width of about 3 feet. Water level in the shaft is at 20 feet. The dump contains much gossan and quartz-pyrite vein matter, and to judge from the dump in general the vein filling was chiefly quartz and first-generation pyrite. (See p. 64.) Some of the material looks like silicified and pyritized wall rock. Calcite, barite, and a trace of sphalerite were noted.

A second shaft lies northeast of the first and just about at the north edge of the metamorphic rocks. Water level in this shaft is at about 30 feet. The shaft is timbered at the collar, and the dip and width of the vein cannot be observed. The dump, which is about half as large as that at the first shaft, contains similar quartz-pyrite material.

The vein is traceable as a prominant gossan in the monzonite to a point about 400 feet beyond the second shaft, where it apparently ends. The outcrop of a parallel vein about 100 feet west begins opposite where the Jowell vein leaves off and can be traced for about 200 feet; it may be the faulted continuation of the Jowell vein.

BADER PROPERTY (LITTLE HATCHET MINING CO.)

The property of A. E. Bader of Hachita lies chiefly along the Sylvanite road just south of Livermore Spring. It includes a group of 34 lode claims known as the Little Hatchet Mining Co., a group of placer claims immediately west, and some other isolated lode claims. The principal workings are indicated as Nos. 15 and 16 on plate 12, and are described below. (See also pl. 20.) The placer claims are described on p. 80.

SANTA MARIA TUNNEL

The most extensive workings on the Bader property are the Santa Maria tunnel, 500 feet south of Livermore Spring, and three associated shafts, as shown on plate 27. Two of the shafts stop at the tunnel level, but one, the Easter Sunday, extends 30 feet below the tunnel and is said to have 200 feet or more of lateral workings at the bottom. The tunnel extends southward about 500 feet and includes nearly 1,000 feet of level workings. The ridge into which it is driven is very low, and the back is probably nowhere more than 60 feet thick. Water level was at 6 to 13 feet below the tunnel in the fall of 1935, but it rises to the tunnel level during rainy seasons.

The workings are 125 to 250 feet in the footwall of the Copper Dick fault. They investigate the badly broken ground near the lower contact of a small mass of metamorphosed shale, limestone, and conglomerate of the Broken Jug limestone in the Sylvanite stock. Sediments and monzonite alike are cut by a multitude of lamprophyre dikes. One of these is followed by the main vein, which has a maximum width of about 4 feet. The vein is broken and offset by several faults, which trend northwestward toward a bend in the Copper Dick fault and which doubtless are spurs from it. Dike and vein appear to have been folded as well as faulted, the vein at some such places pinching out completely in the sheeting of the lamprophyre, but whether the vein actually has been pulled apart along the folds or whether such places indicate the original limits of a vein lens is not known.

The vein matter is considerably oxidized but apparently consisted originally chiefly of quartz, calcite, barite, chalcopyrite, and pyrite. To judge from the oxidized ore piled on the dump, some of the chalcopyrite must have been very massive and have formed slabs as much as a foot thick. Massive barite is common at two places along the vein, and the chalcopyrite appears to have been most abundant there. Molybdenite and epidote were observed locally. Pods and discontinuous stringers of quartz and calcite are

[10] Hill, J. M., in Lindgren, Waldemar, op. cit. (U. S. Geol. Survey Prof. Paper 68), p. 343.

exposed in the monzonite and lamprophyre in some of the crosscuts, and the pods contain pockets of actinolite and chlorite like those in the gold veins of the district.

Ore has been mined from a small driftlike stope below the level at one of the barite-rich places, but none has been shipped. Several piles of ore, aggregating perhaps 3 or 4 cars, have been collected on the surface, and Bader estimates that this material contains about 20 percent of copper, 10 ounces of silver a ton, and 0.25 ounce of gold a ton.

FARIA WORKINGS

The Faria workings include the Faria shaft and other more shallow workings a few hundred feet southeast of the Santa Maria tunnel and over the ridge. The Faria shaft, which is inaccessible because of bad timbers, is stated to be 175 feet deep and was started as a prospecting shaft in the barren metamorphosed beds of the same mass prospected by the Santa Maria tunnel. The bottom of the shaft likewise is in the sediments, but monzonite was cut on the way down. Bader says that a vein striking a little north of east and dipping steeply northward is exposed in the bottom of the shaft. It is 1 to 2 feet wide and, as indicated by a pile of ore on the dump, consisted of stringers of calcite veined or intergrown with epidote and containing threads, blebs, and disseminated grains of pyrite, pyrrhotite, and molybdenite. A sample from the vein is said to have indicated 0.9 ounce of gold a ton.

Forty feet north of the Faria shaft, and also in the sediments, are a few shallow workings on a copper-bearing vein zone that trends N.60° W. and whose major members dip southwest at 60°. The piles of ore contain copper carbonates, chrysocolla, chalcocite, limonite boxwork, and much of the massive varnish-like variety of limonite indicative of chalcopyrite. The deepest working is a 35-foot shaft that exposes a 1-foot oxidized vein having a pocketlike extension into the hanging wall along a contact between garnetite and a silicated shale-conglomerate bed. A ½-inch to 5-inch stringer containing quartz, calcite, magnetite, and minor epidote and chlorite lies along the wall of the pocket and extends below it for a few feet.

An open cut 60 feet west of the shaft, and apparently along the trend of the shaft vein, exposes several feet of crushed rock in the hardened shale, and just above that a 15-foot tunnel exposes a vertical 1-foot vein of oxidized material.

SILVER TRAIL TUNNEL

The Silver Trail tunnel is a quarter of a mile southwest of the Faria workings and 50 feet east of the Copper Dick fault. It includes an inclined tunnel and its lateral workings, the whole totaling about 110 feet in April 1936, which prospect an almost horizontal vein lying along a sheared and schistose lamprophyre dike, the dike in turn following a thin slice of metamorphosed sediments in the Sylvanite stock. The vein, which strikes N.80°E. and has an average dip of 15° N., was commonly 2 to 8 inches wide as exposed at the time of my visit, though containing swellings or pods several times that width. Gouge, breccia, and sheared rock, aggregating from a few inches to as much as 4 feet in thickness, accompany the vein.

For the first 20 feet from the portal the vein and associated fault matter lie within the lamprophyre dike, with monzonite and a little garnet rock exposed in the roof above the lamprophyre, but monzonite forms the immediate hanging wall of the vein from there in, and the lamprophyre dike, which is as little as 8 or 10 inches thick, forms the footwall. At one place the vein is displaced 2½ feet by a small fault zone that strikes northeast and dips 65°SE.

The vein matter consists predominantly of coarse-grained calcite, but includes also the familiar white quartz, chlorite, and actinolite of the Sylvanite veins, as well as argentiferous galena, pyrite, and various oxidation products, among which are cerussite, smithsonite, stains and crusts of mottramite, needles of mimetite, and stains of copper carbonates. The galena in part occupies fairly pure streaks as much as 8 inches wide. A thick pod of calcite in which are distributed blebs of pyrrhotite containing galena, chalcopyrite, and microscopic particles of sphalerite, is exposed in the face of one of the openings.

Two tons of sorted galena ore has been shipped, the shipment averaging 0.05 ounce of gold a ton, 75 ounces of silver a ton, and 41 percent of lead.

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INDEX